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Gemma Dale

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Answers are available in the Online Teaching Suite.
Teachers can enable or disable answers in their students' accounts.

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How to use this resource

Elements in the print book

Glossary
Definitions of key terms are provided next to where the key terms first appear in the chapter.

Explore!

Students are encouraged to conduct research online to find and interpret information.

Quick check

These provide quick checks for recalling facts and understanding content. Cognitive verbs appear in bold. These questions can be completed in the Interactive Textbook or downloaded as Word documents.

Learning goals

These are descriptions of what the student will learn throughout the section.

Did you know?

These are short facts that contain interesting information.

Science inquiry

These are recent developments in the particular area of science being covered. They may also show how ideas in science have changed over the years through human discovery and inventions.

Section questions

Question sets at the ends of sections are categorised under five headings: Remembering, Understanding, Applying, Analysing and Evaluating. Cognitive verbs appear in bold.
These questions can be completed in the Interactive Textbook or downloaded as Word documents.

Hands-on activities

Try this

Classroom activities help explore concepts that are currently being covered.

Making thinking visible

Visible-thinking-style classroom activities help consolidate the concepts currently being covered.

Practical

These activities focus on developing science inquiry skills, including using laboratory equipment. These activities are also available as Word document downloads in the Interactive Textbook.

Worked example

Worked examples are provided for topics that require calculations, or to reinforce important skills.

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End-of-chapter features

Chapter review

Chapter checklist

Success criteria		Linked questions
2.1	I can recall the components that make up the structure of DNA and RNA molecules.	6, 13
2.1	I can describe the relationship between genes, DNA and chromosomes.	1
2.1	I can describe the steps in which DNA is used to synthesise proteins.	7, 18
2.2	I can recall the steps involved in DNA replication.	3, 4, 15
2.2	I can describe the stages of cell division in mitosis.	17
2.2	I can describe the stages of cell division in meiosis.	17
2.2	I can use a karyotype to determine information about an individual.	10
2.3	I can define the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive' with respect to genetic inheritance.	5
2.3	I can use and interpret a Punnett square to identify possible genotypes and phenotypes of offspring.	20, 23
2.3	I can explain sex linkage.	11, 19
2.3	I can distinguish between codominance and incomplete dominance.	22
2.3	I can use a pedigree diagram to determine the type of inheritance that is occurring.	19
2.4	I can explain the different types of mutations, including their causes and effects.	16
2.4	I can describe some ways in which DNA can be manipulated.	25

Chapter checklists help students check that they have understood the main concepts and learning goals of the chapter. Checklists can be downloaded from the Interactive Textbook.

Chapter review question sets are categorised under five headings: Remembering, Understanding, Applying, Analysing and Evaluating. These questions can be completed in the Interactive Textbook or downloaded as Word documents.

Data questions

A student prepared an onion root tip slide and examined the cells using a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

Stage of cell cycle	Number of cells recorded
Interphase	340
Prophase	13
Metaphase	4
Anaphase	3
Telophase	6

Table 2.6 Number of onion cells in each stage of the cell cycle

Data questions help students apply their understanding, as well as analyse and interpret different forms of data linked to the chapter content. These questions can be completed in the Interactive Textbook or downloaded as Word documents.

110 Chapter 2 GENETICS

STEM activity: DESIGNING AND PROTOTYPING AN ASSISTIVE DEVICE ... 111

STEM activity: Designing and prototyping an assistive device for individuals with a genetic disease

Background information

When a mutation occurs that is not beneficial, complications occur. An example of a disease with genetic causes is scoliosis. Scoliosis is a sideways curvature of the spine that usually occurs before puberty. Genetic diseases such as cerebral palsy and muscular dystrophy can cause scoliosis, but the cause of most cases of scoliosis is unknown.

Figure 2.68 Various brace designs can be used for the treatment of scoliosis.

DESIGN BRIEF

Research a genetic disease. Design and build an apparatus that can help to improve the quality of life of people with the selected disease.

Activity instructions

In groups of three or four, conduct basic research on a genetic disease. Then design an apparatus that will improve the quality of life of people with that condition. Consider how the product would be built and marketed. Each team member needs to have a clear role but must be able to contribute to all aspects of the project.

Suggested materials

- computer
- pencil
- paper
- ruler
- balsa wood
- plaster
- papier mâché
- chicken wire
- 3D printer
- cardboard
- poster paper

Research and feasibility

1. Research genetic diseases and as a group decide which genetic disease will be the focus.
2. Create a table of the causes and effects of the disease.

Genetic disease cause	Effects on part of body	Ideas to help
e.g. Muscular dystrophy Muscle loss	Reduced joint movement	Brace and orthotics for feet
e.g. Haemophilia Blood doesn't clot effectively	Whole body can be bruised easily	1. Creation of children's play suit 2. Creation of some type of buffing edging that could be applied to furniture

3. Find pictures or diagrams of current equipment used, and annotate them with features and characteristics that relate to assisting people living with this disease.

Design and sustainability

4. Sketch potential design solutions (at least two) and annotate the purpose of the apparatus and what it is made of. Describe how it will improve the quality of life for people with this disease. How will it improve on current aids or tools (if any)?
5. Reflect on the materials you would use in real-world construction and comment on the durability and sustainability of the materials.

Create

6. Build a prototype of your design using available construction materials.

Evaluate and modify

7. Reflect on the prototype you have created and its effectiveness to help people with your chosen genetic disease.
8. Discuss as a group the modifications you would make in your solution to increase the effectiveness of design.
9. Present your prototype to the class. Outline the effectiveness of the prototype and demonstrate supporting ideas that show how the prototype would improve the quality of life of a person with this genetic disease.

STEM activities encourage students to collaboratively come up with designs and build solutions to real-world problems and challenges.

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Links to the Interactive Textbook (ITB)

VIDEO
These icons indicate that there is a video in the Interactive Textbook.

WIDGET
These icons indicate that there is an interactive widget in the Interactive Textbook.

These icons indicate that worksheets, activities or question sets can be downloaded from the Interactive Textbook.

QUIZ
Automarked quizzes can be found in the Interactive Textbook for every section.

SCORCHER
Competitive questions can be found in the Interactive Textbook for every chapter review.

These icons indicate that questions can be completed in workspaces in the Interactive Textbook.

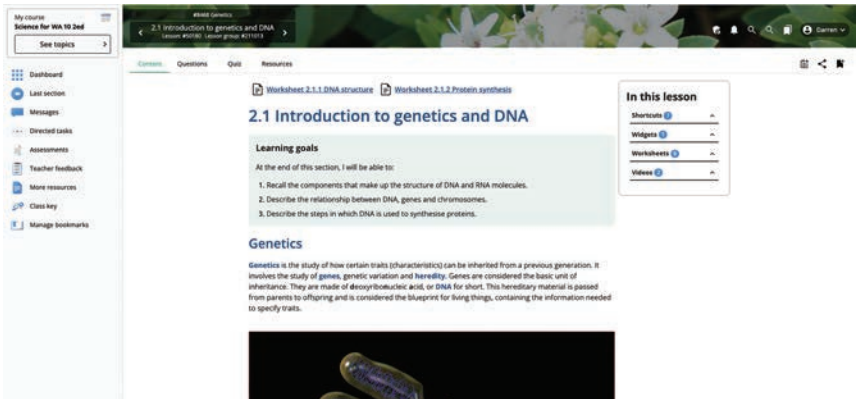
Overview of the Interactive Textbook

The **Interactive Textbook (ITB)** is an online HTML version of the print textbook, powered by the Edjin platform. It is included with the print book or available as a separate digital-only product.

Definitions pop up for key terms in the text.

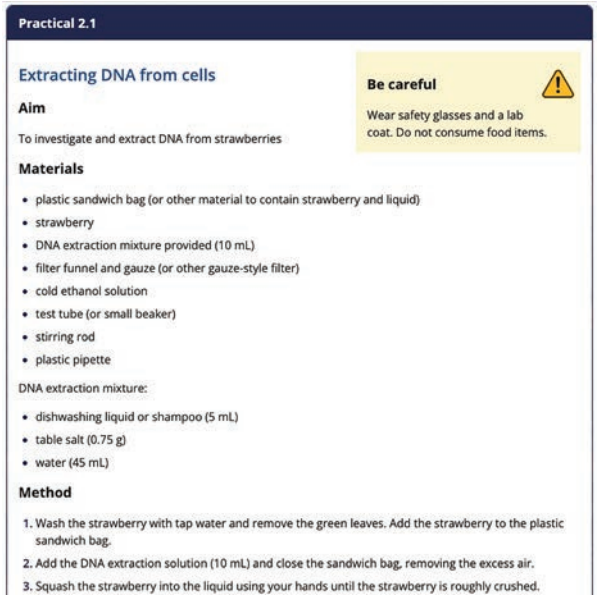
Quizzes contain automarked questions that enable students to quickly check their understanding.

Worksheets are provided as downloadable Word documents.



Videos summarise, clarify or extend student knowledge.

Widgets are accompanied by questions that encourage independent learning and observations.


Practical 2.1
Extracting DNA from cells
Aim
To investigate and extract DNA from strawberries
Be careful
Wear safety glasses and a lab coat. Do not consume food items.
Materials
plastic sandwich bag (or other material to contain strawberry and liquid)
strawberry
DNA extraction mixture provided (10 mL)
filter funnel and gauze (or other gauze-style filter)
cold ethanol solution
test tube (or small beaker)
stirring rod
plastic pipette
DNA extraction mixture:
dishwashing liquid or shampoo (5 mL)
table salt (0.75 g)
water (45 mL)
Method
1. Wash the strawberry with tap water and remove the green leaves. Add the strawberry to the plastic sandwich bag.
2. Add the DNA extraction solution (10 mL) and close the sandwich bag, removing the excess air.
3. Squash the strawberry into the liquid using your hands until the strawberry is roughly crushed.

Practicals are available as Word document downloads, with sample answers and guides for teachers in the Online Teaching Suite.

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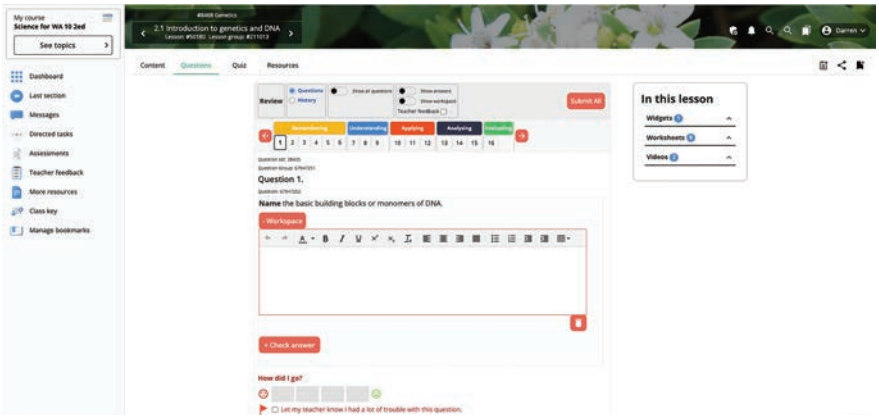
Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

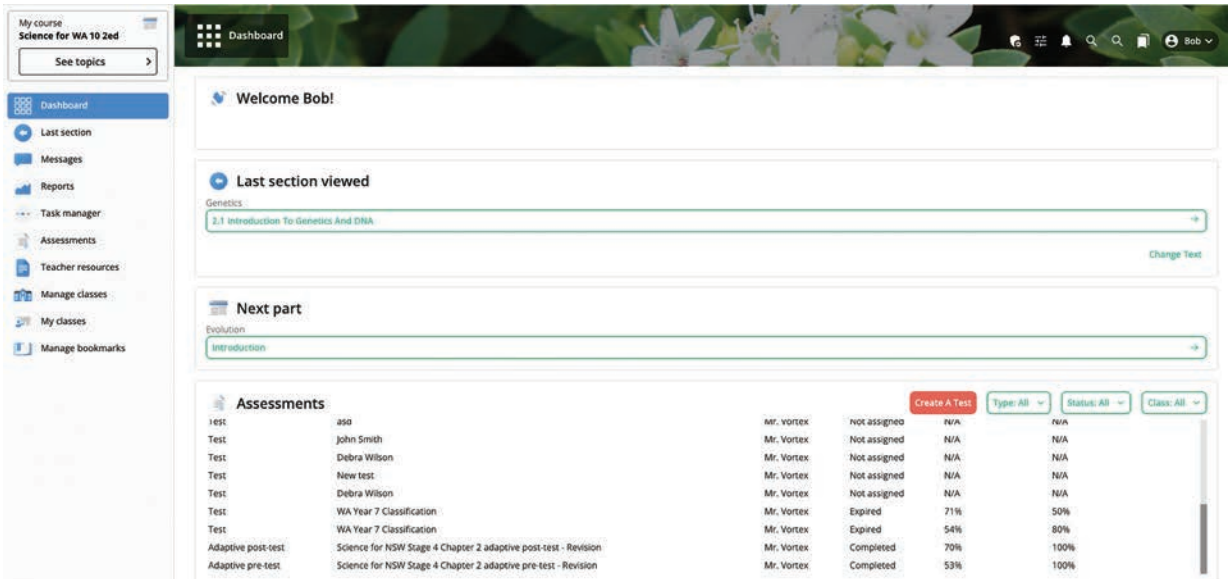
Self-assessment tools enable students to check answers, mark their own work and rate their confidence level in their work. Student accounts can be linked to the learning management system used by the teacher in the Online Teaching Suite.



Overview of the Online Teaching Suite (OTS)

The **Online Teaching Suite (OTS)** is automatically enabled with a teacher account and is integrated with the teacher's copy of the Interactive Textbook. All the assets and resources are in one place for easy access. The features include:

- the **Edjin learning management** system with class and student analytics and reports, and communication tools
- teacher's view of **students' working and self-assessment**
- **chapter tests** and **worksheets** as PDFs and as editable Word documents with answers
- editable **curriculum grids** and **teaching programs**
- **teacher notes** (including suggested responses if relevant) for Practicals, Try this, Making thinking visible, Explore! and STEM activities
- **adaptive tools**, including ready-made pre- and post-tests and intuitive reporting.



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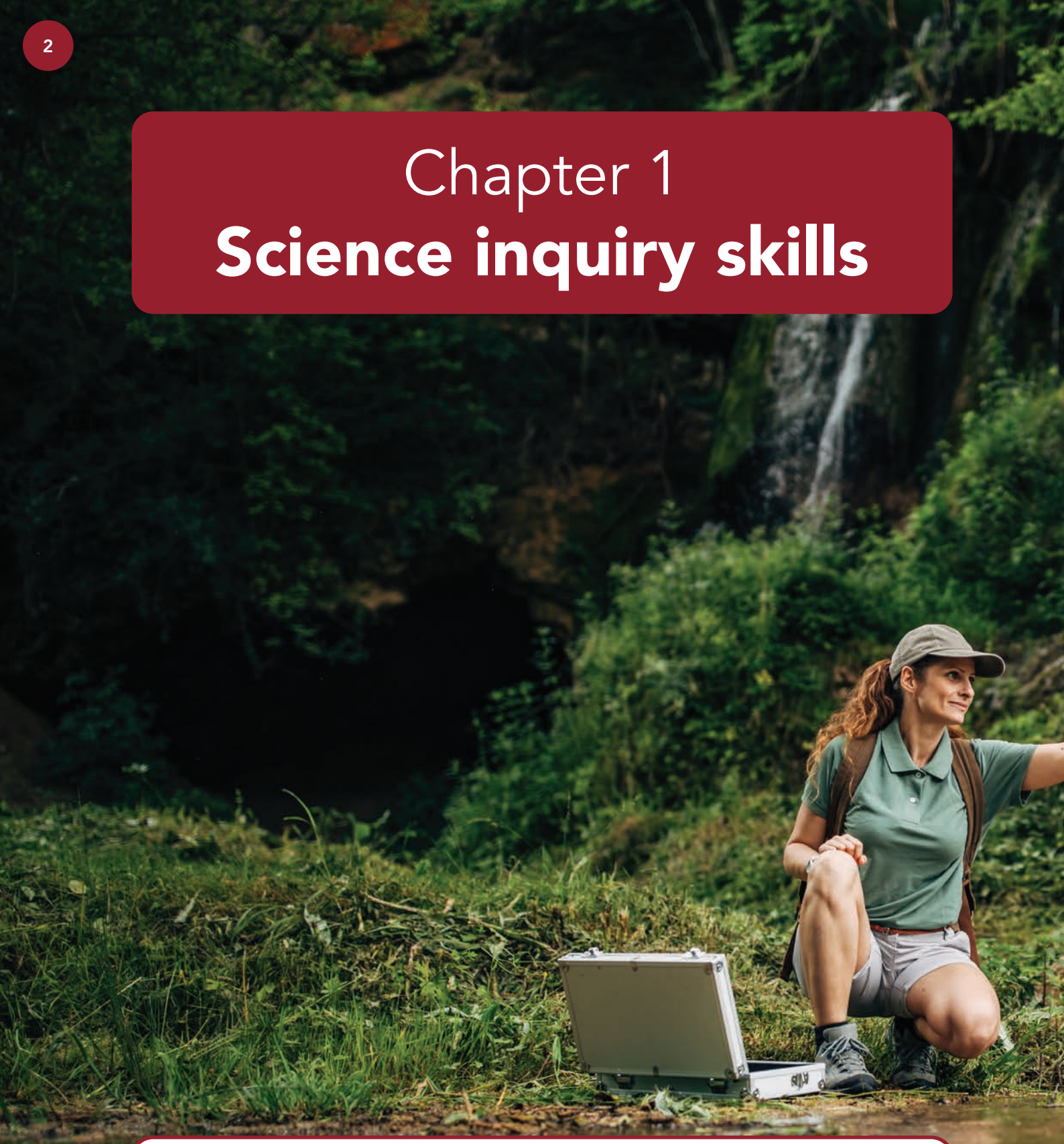
Chapter 1
Science inquiry skills



Chapter introduction

Making a scientific claim requires compelling scientific evidence, which can only be produced by the rigorous planning and conducting of scientific experiments. This chapter will guide you through the investigative process of career scientists, from reviewing the work of their peers to providing reliable and valid evidence to test hypotheses. You will explore the safety and ethical implications of experimentation, as well as the role of specialised equipment and computers analysing large data sets.

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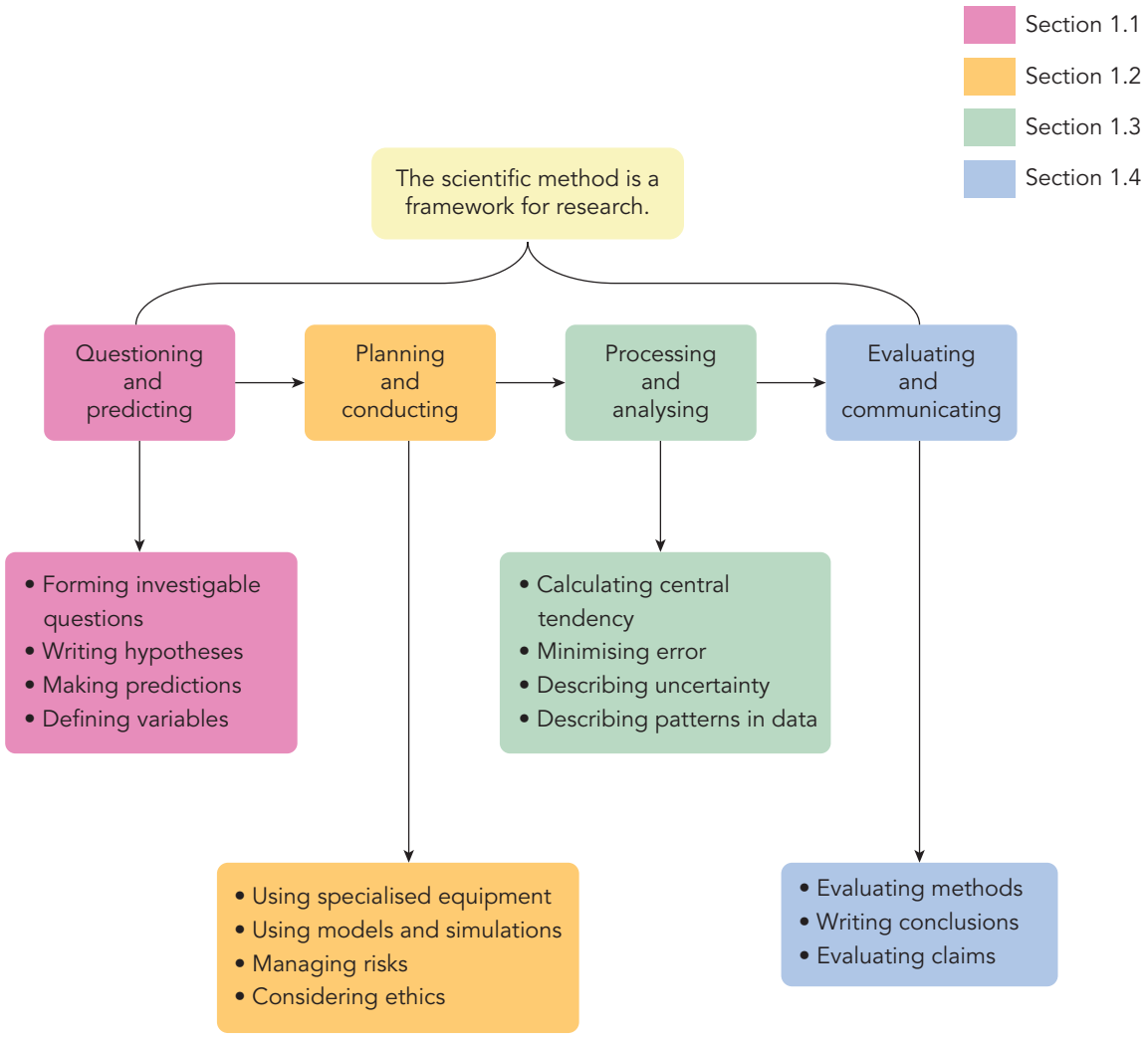
Chapter map



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Curriculum content

Questioning and predicting	
Propose investigable questions and hypotheses to test relationships and develop explanatory models	1.1
Planning and conducting	
Plan and conduct valid and reproducible investigations to answer questions and test hypotheses, developing and following risk assessments, and considering ethical issues	1.1, 1.2
Select and use equipment to generate and record data with precision to obtain appropriate sample sizes and replicable data, using digital tools as appropriate	1.2
Processing, modelling and analysing	
Select and construct appropriate representations, including tables, graphs, descriptive statistics, models and mathematical relationships, to organise and process data and information	1.3
Analyse and connect a variety of data and information to identify and explain patterns, trends, relationships and anomalies, and draw conclusions based on evidence	1.3
Evaluating	
Evaluate validity and reliability of methods and validity of conclusions, including identifying possible sources of error, and describe specific ways to improve the quality of the data	1.3, 1.4
Construct arguments based on analysis of a variety of evidence to support conclusions or evaluate claims	1.4
Communicating	
Communicate scientific ideas and information for specific purposes and audiences, including constructing evidence-based arguments and selecting appropriate content, language and text features, using digital tools as appropriate	1.4

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Glossary terms

absolute uncertainty
accuracy
bivariate analysis
confidentiality
confounding variable
controlled variable
correlation
cultural appropriation
dependent variable
ethics
fair test
hypothesis
implicit bias
independent variable
inference
informed consent
investigable question
mean
median
mode
model
outlier
parallax error
plagiarism
precision
prediction
qualitative
quantitative
random error
reading error
relative uncertainty
reliability
repeatability
replicability
reproducibility
right to withdraw
simulation
systematic error
titration
univariate analysis
validating
validity
variable
zero calibration error

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1.1 Questioning and predicting

Learning goals

At the end of this section, I will be able to:

1. Propose investigable questions.
2. Distinguish independent, dependent and controlled variables in a scientific investigation.
3. Write an appropriate scientific hypothesis.
4. Differentiate between reliability, replicability and reproducibility.

WORKSHEET Energy drinks and reaction time

WORKSHEET Testing the effectiveness of fertilisers

Step 1. Observe and ask questions

The scientific method starts with observation, where scientists gather information using their senses, such as 'The person looks tired' or 'The coffee smells strong'. These observations are factual, without opinions or explanations. Based on these observations, scientists make **inferences**, which are logical explanations drawing on past knowledge. For example, seeing someone yawning might lead to the inference that they didn't sleep well.

inference to link an observation with past knowledge in a logical explanation and assign meaning to the observation

Inferences help form **investigable questions** that can be tested through experiments, such as 'Does caffeine intake improve reaction times?' These questions must be specific, measurable and testable. Non-investigable questions, like 'Why do people enjoy coffee?', are too broad or subjective for experimentation. Choosing the right question depends on factors like access to equipment, time and other resources to ensure it's practical for scientific investigation.

investigable question a research question that can be answered through completing an experiment

Step 2. Do background research

Before designing an experiment, it's essential to check if similar questions have already been investigated. Conducting background research using secondary sources helps refine your question and ensures it hasn't already been answered. For example, if you're studying how caffeine impacts study performance, you might find research on how different amounts of caffeine affect concentration. This step involves identifying key terms, developing clear research questions and finding trustworthy sources to gather relevant information.

Figure 1.1 'Does a flat white or long black taste better?' is a non-investigable question … although it's something you might debate with friends!

Experimental **validity** assesses whether the experiment is suitable for the research question and measures what it claims to measure. That is, does the experiment manipulate only the independent variable and measure only the dependent variable with all other variables kept constant? You may recall from previous years that validity is often associated with whether the experiment conducted was a 'fair test'. For example, an experiment that is testing the effect of temperature on enzyme action should not have one set of enzymes at 20°C and pH 4, and another at 40°C and pH 9. The effect could be due to the difference in pH rather temperature. The validity of an experiment depends on both the experimental design and the procedure. This principle applies to both experiments you conduct yourself and secondary sources you use in designing experiments and constructing scientific arguments.

validity the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what is says it measures

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variable
a factor or condition that can be controlled, changed or measured in an experiment

reliability
how repeatable, replicable and reproducible the results are

repeatability
how well the results match up when the same scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

replicability
how well the results match up when a different scientist repeats the experiment using the same method as the original experiment, in a different laboratory or field site

reproducibility
how well the results match up when a different scientist repeats the experiment under different conditions to the original experiment, with a different method, equipment and laboratory or field site

Reliability, repeatability, replicability and reproducibility

To state whether an experiment has provided 'valid' results, the experimenter must consider the influence of any loosely controlled **variable** or uncontrolled variables, rather than how much data was collected. Results might be 'reliable' but not 'valid' if a confounding variable was not controlled in the method. It is important that scientists are very strict in controlling the controlled variables to ensure the validity of their results.

When assessing the validity of experimental results or information from secondary sources, it's crucial to also evaluate its **reliability**. Reliable results typically come from experiments with large sample sizes and outcomes that are repeatable, replicable and reproducible. Experiments that rely on subjective data or small sample sizes are less reliable. For example, deciding whether a new painkiller should be prescribed to all Australians based on one person's experience would be unreasonable.

Single experiments may not provide reliable evidence because uncontrolled variables can introduce uncertainty. To improve reliability, scientists repeat experiments under the same conditions – this is known as conducting multiple trials. If a scientist achieves consistent results using the same method and equipment, the experiment has high **repeatability**.

Reliable results should also have **replicability**, meaning other scientists can repeat the experiment with the same method and equipment and get similar outcomes. Furthermore, results should have **reproducibility**, which means another scientist using different methods or equipment should still obtain comparable results. When results are repeatable, replicable and reproducible, scientists can be confident in their reliability.

This is why your teacher encourages repeating experiments: to identify outliers, average results and ensure confidence in your findings.

	Repeatable	Replicable	Reproducible
Consistent results from:	Same person Same lab Same method	Different person Different lab Same method	Different person Different lab Different method

Table 1.1 The difference between repeatability, replicability and reproducibility

Quick check 1.1

1. **Identify** the correct words to complete the following sentences.
   a) Using the same set of scales when measuring the mass of a beaker on day 1 and day 2 of an experiment is a factor relating to the _____ of an experiment.
   b) When another scientist performs the same experiment in a different lab and gets the same results the experimental results have _____.
2. **Explain** the importance of reproducing experiments in the field of science.

Reliable sources

Experimental validity focuses on whether an experiment is designed to accurately measure what it intends to, by ensuring only the independent variable is manipulated and the dependent variable is measured, with all other factors controlled. Similarly, when evaluating the validity of online content, it's essential to apply similar criteria to ensure the information is both reliable and accurate. Consider factors such as the author's qualifications, the accuracy of the information and the presence of supporting evidence.

Scientific journals ensure that all published reports of research are reviewed by other independent scientists working in the same field to check for unreliable data, or invalid conclusions or errors. This is an important quality-control step in science called 'peer review'.

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Reliable sources are typically written by experts, such as scientists or scholars, and are published in reputable journals, books or websites. Check the publication date to ensure the information is up-to-date, as outdated data may no longer be accurate. Consider the purpose of the source – whether it aims to inform, persuade or sell – and be cautious of bias, which can distort facts. Cross-referencing information with other credible sources can also help confirm its accuracy.

Figure 1.2 *Nature* is one of the most cited scientific journals, making it one of the most respected academic journals globally.

Step 3. Identify the variables

The goal of an investigation is to answer a research question by systematically collecting and analysing data. For instance, you might investigate how different study techniques affect test scores. Defining a clear purpose keeps the investigation focused. In an experiment, the **independent variable** is what you deliberately change, such as the amount of time spent studying, and the **dependent variable** is what you measure, like the test results. **Controlled variables**, such as the difficulty of the test, must remain constant to ensure a **fair test**.

For example, in an experiment testing whether the number of hours of sleep affects reaction times, the independent variable is the amount of sleep, and the dependent variable is how quickly someone reacts. The controlled variables might include the time of day at which the test is conducted and the participants' activity level before the test, which should remain the same to ensure accurate results.

independent variable
the variable that is deliberately changed during an experiment

dependent variable
the variable that is measured during an experiment (as it responds to the independent variable)

controlled variable
a factor that remains constant throughout an experiment to ensure that any changes observed in the dependent variable are solely due to the manipulation of the independent variable

fair test
an experiment where all variables are kept constant except for the independent variable being tested

Did you know? 1.1

Scientific publishing crisis

Scientific knowledge is verified through rigorous processes such as hypothesis testing and peer review. Hypothesis testing involves proposing a testable explanation and conducting experiments to gather data that supports or refutes the hypothesis, while peer review ensures that other experts critically assess the research methods and findings before publication.

However, these verification processes are being undermined by a growing global crisis in scientific publishing. In 2023, over 10 000 sham research papers were retracted, exposing the widespread issue of fraudulent studies largely driven by shadow organisations known as 'paper mills'. These paper mills produce fake research to advance the careers of young scientists, often bribing journal editors or infiltrating editorial boards. The result is a rise in retractions, which have increased from just over 1000 in 2013. This scandal undermines scientific progress and threatens credible research, making it difficult for scientists to base their work on trustworthy findings.

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confounding variable an external factor that can unintentionally affect the outcome of an experiment, making it difficult to determine whether changes in the dependent variable are caused by the independent variable

qualitative a form of data that is a descriptive measurement

quantitative a form of data that is a numerical measurement

precision how closely repeated measures agree with each other

univariate analysis examining the characteristics of a single variable to understand its distribution and key features

bivariate analysis investigating the relationship between two variables to determine how changes in one variable might affect the other

hypothesis an educated guess that can be tested through further experimentation

prediction a statement that describes what is expected to happen if the hypothesis is true

It's important in the results of an experiment to consider **confounding variables** – variables that were not controlled, but have unintentionally influenced the results. In the sleep and reaction time experiment, suppose it turned out that some participants had drunk coffee just before the experiment; this could be a confounding factor. As it was not controlled, it could undermine the validity of the experiment, even if the data appears reliable, and needs to be reported in the discussion of the results. To determine whether an experiment has provided valid results, the experimenter must evaluate the influence of any confounding variables, rather than simply focusing on the volume of data collected. Results may be reliable but not valid if confounding variables are not controlled in the experimental design. Therefore, it is essential for scientists to rigorously control all variables to ensure the validity of their findings.

Data types

Different investigations require different types of data. **Qualitative** data might describe a person's mood during a test, while **quantitative** data could include the number of correct answers. The setting or context of data collection must be appropriate – field observations of natural behaviour might offer real-world insight, whereas a controlled lab study on cognitive tasks ensures **precision**. For instance, studying how noise levels impact concentration would be more precise when noise levels can be controlled in a laboratory rather than in a noisy public space where the levels may vary too much from moment to moment.

When carrying out data analysis, you can use **univariate analysis**, which focuses on understanding a single variable, like average reaction time, or **bivariate analysis**, which looks at the relationship between two variables, such as sleep hours and reaction time. This should be part of the experimental design and helps ensure that the results address the research question clearly.

Step 4. State a hypothesis and make a prediction

A **hypothesis** is an educated guess based on existing knowledge and is written as a testable statement. For instance, 'If people consume caffeine before studying, then their test scores will improve'.

Predictions outline what is expected to occur if the hypothesis is true, guiding the design of the experiment and the collection of data. For example, 'Students who drink coffee before studying will score an average of 10 points higher on their tests than those who do not consume caffeine'.

When hypotheses are tested and their predictions are confirmed by experiment, they can be used to guide further research to develop explanatory models for phenomena and observations. In this example, the explanatory model might be how caffeine improves test scores, for example does it speed up thinking time or recall from memory.

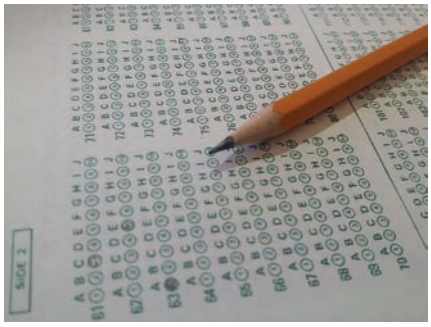

Figure 1.3 A univariate analysis would involve analysing the test scores of students in a class that could provide insights into the average performance and the spread (range) of scores. A bivariate analysis would study whether changes in exam scores are associated with changes in the number of hours studied, to reveal whether more study time is associated with higher test performance.

Constructing a hypothesis				
Formula:	If	state the change in the **independent variable**	then	state the expected change in the **dependent variable**.
Example:	If	**caffeine intake** is increased	then	test scores will improve
Hypothesis: If people consume caffeine before studying, then their test scores will improve.				

Table 1.2 How to construct a hypothesis using an 'If … then …' statement.

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Section 1.1 review

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Section 1.1 questions

Remembering

1. **Define** the term 'investigable question' and provide an example.
2. **Recall** the meaning of the term 'controlled variable' and explain its importance in an experiment.

Understanding

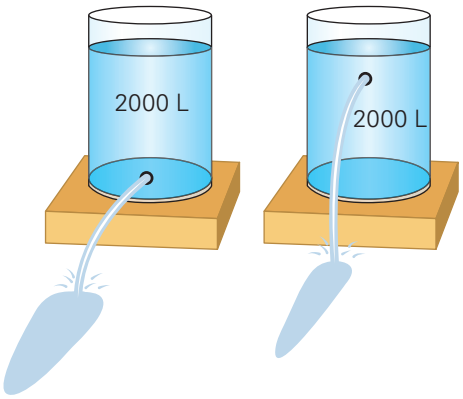
3. **Summarise** the importance of conducting background research before designing an experiment.
4. **Describe** the difference between repeatability, replicability and reproducibility in experimental results.

Applying

5. **Apply** the concept of controlled variables by designing a simple experiment involving plant growth.
6. **Compare** the use of qualitative and quantitative data in the context of a scientific investigation.

Analysing

7. **Analyse** the potential confounding variables in an experiment measuring the effect of study time on test scores.
8. A farmer noticed that his leaky tanks seemed to lose water quicker if the hole was closer to the bottom of the tank. He designed the following research question: Do tanks leak water faster when the hole is positioned lower on the tank?
   a) **Identify** the independent variable of this experiment.
   b) **State** three variables that must be controlled.
   c) The farmer repeated his experiment on five different occasions and found the same result: the water flows more strongly from the lowest hole in a water tank. **Identify** whether this demonstrates high or low repeatability and validity.



Evaluating

9. **Assess** the reliability of a study that concludes that caffeine has no effect on reaction times based on a small sample size.
10. **Critique** an experimental design that does not account for confounding variables and discuss how this could affect the results.
11. **Evaluate** the importance of peer review in the scientific publishing process and its impact on research credibility.

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1.2 Planning and conducting investigations

WORKSHEET Conducting an investigation

titration a procedure or technique used to determine the concentration of an unknown solution

accuracy how closely measures match the 'true' or accepted values

Learning goals

At the end of this section, I will be able to:

1. Select and use specialised scientific equipment such as titration equipment and data loggers.
2. Describe the use of models and simulations.
3. Identify and manage risks and ethical issues in an experiment.

Step 5. Outline the method and equipment needed

Selecting suitable materials and technologies is crucial for the success of any investigation. Using high-quality and appropriate tools, such as a balance for precise mass measurements, ensures reliable and valid results. In some cases, specialised equipment may be required to achieve precise measurements or to conduct specific procedures. For instance, a burette is essential in **titrations**, allowing for accurate delivery of liquid reagents. Incorporating data loggers and probes into experiments can enhance the **accuracy** of measurements by providing real-time data collection and monitoring, ultimately improving the overall quality of the investigation.

Titrations

Titration is a specialised procedure used in chemistry to determine the concentration of an unknown solution. It involves measuring the volume of one solution (typically an acid or a base) that is needed to neutralise a carefully measured amount of a second solution. Titrations require specialised equipment such as a pipette, burette, pH probe or data-logging device.

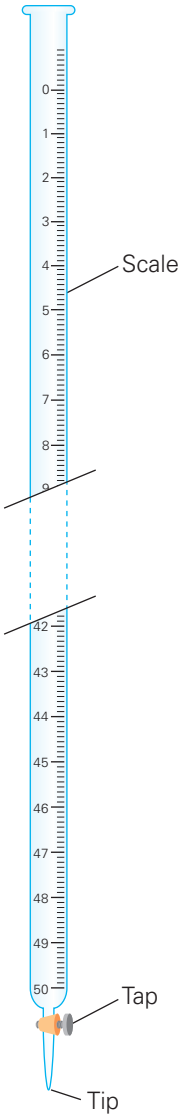

Figure 1.4 A burette

Figure 1.5 A burette in a retort stand being used to perform a titration

A pipette is an important tool to use within the laboratory, as very small amounts of solution can be measured out accurately. Pipettes are made in different sizes to deliver a specific volume. A burette is a long, thin glass tube used to measure the volume of solution needed for the titration reaction (see Figure 1.4). A burette can release the solution into a flask when its tap is turned. To release the solution, the tap is placed in a vertical position, and to stop the flow, the tap is placed in a horizontal position (see Figure 1.5). The volume of solution added to the flask is called the titre.

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Instructions for using a pipette

To use a pipette to deliver a fixed volume of solution, a pipette pump is attached to help fill and empty the pipette with solution (see Figure 1.6).

1. Attach the pipette pump to the end of the pipette by gently twisting and securing it.
2. Turn the thumb wheel on the pipette pump to allow the solution to be drawn into the pipette.
3. Rinse the pipette using a small amount of the solution being used.
4. Draw up the solution above the volume mark of the pipette.
5. Release the solution from the pipette until the bottom of the curve of the meniscus sits just on top of the volume mark.
6. Now you are ready to deliver an accurate volume of your solution.

HINT: When drawing the solution up into the pipette, make sure the tip is always in the solution to prevent bubbles being drawn up into the pipette.

A pipette bulb (see Figure 1.7) may be used in place of a pipette pump to draw up and deliver solutions.

There are a few important things to remember when using a pipette bulb:

- When inserting the pipette, hold the pipette close to the end being inserted so that the pipette does not break.
- To create a seal, do not insert the pipette too far into the bulb (1 cm should be enough).
- Never allow solution to enter the bulb. Tell your teacher immediately if this occurs.
- Make sure there is more than enough solution in the beaker to draw up into the pipette.
- Be careful when removing the pipette from the bulb at the end of an experiment. A gentle twisting motion will help you remove the pipette safely without breaking it.

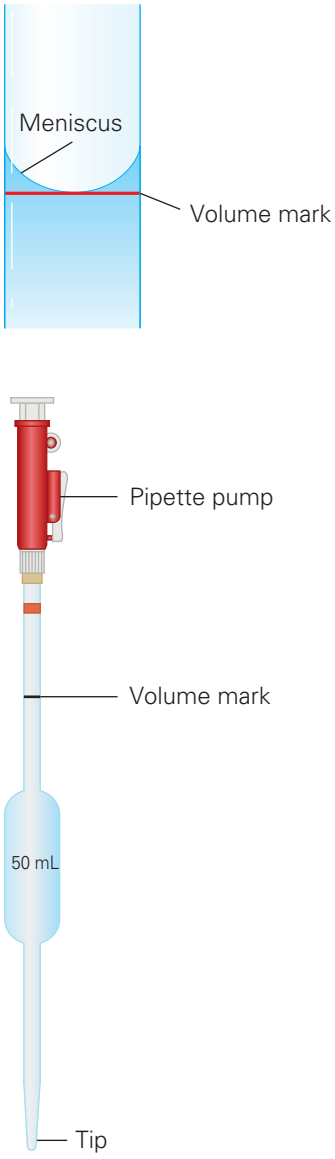

Figure 1.6 A 50 mL volumetric pipette and pipette pump

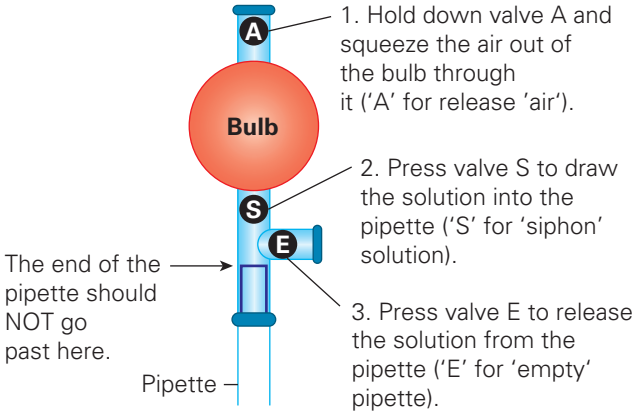
A
Bulb
S
E
1. Hold down valve A and squeeze the air out of the bulb through it ('A' for release 'air').
2. Press valve S to draw the solution into the pipette ('S' for 'siphon' solution).
3. Press valve E to release the solution from the pipette ('E' for 'empty' pipette).
The end of the pipette should NOT go past here.
Pipette

Figure 1.7 The correct way to use the three valves in a pipette bulb. Valves 'A', 'S' and 'E' are sometimes labelled as '1', '2' and '3', respectively. Note that the pipette has been inserted less than 1 cm into the bulb.

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VIDEO
Titration skills

Practical 1.1

Titration skills

Be careful
Wear gloves, safety glasses and a lab coat.

Background

Specialised equipment like burettes, pipettes and data loggers are essential in many scientific fields. Burettes are long, graduated glass tubes used for delivering accurate volumes of liquid, typically in chemistry experiments. They are commonly used in titrations, where a small volume of one solution is slowly added to another solution until the reaction is complete. Burettes allow for precise control over the amount of liquid added, enabling accurate results. Pipettes (see Figure 1.6) are like burettes, but they are smaller and used for measuring a set volume of liquid.

Aim

To practise using a burette and pipette.

Materials

- 100 mL of 0.1 mol L^{-1} sodium hydroxide solution
- 20 mL of 0.1 mol L^{-1} hydrochloric acid solution
- 2 or 3 drops phenolphthalein indicator
- 100 mL beakers ×3
- burette
- 20 mL pipette
- pipette pump
- funnel
- conical flask
- retort stand
- clamp
- white tile (to help detect colour change)

Method

Part 1: Practising reading from a burette

1. When reading from the burette, always record volumes to two decimal places. For example, if a reading is exactly on the 2.7 mL mark, it should be recorded as 2.70 mL.
2. Try the example in Figure 1.8. It would be read as 1.32 mL.

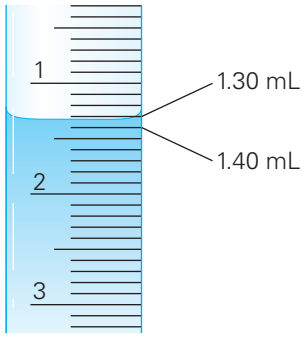

Figure 1.8 Reading a burette to two decimal places

3. To calculate the titre volume (amount added to the flask), write down the initial and final burette readings and then subtract the final reading from the initial reading.

continued ...

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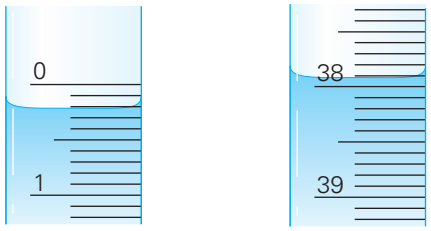
4. Calculate the titre volumes in the following examples.

Example 1

Titre = final reading – initial reading

Titre = 37.91 mL – 0.21 mL

Titre = 37.70 mL



Initial reading: 0.21 mL Final reading: 37.91 mL

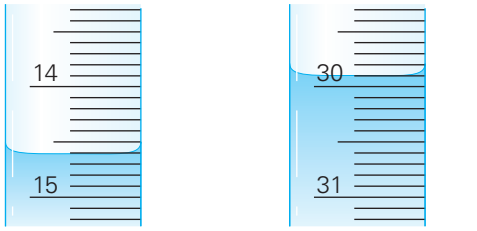
Figure 1.9 Calculating a titre volume from burette readings (Example 1)

Example 2: Try this one yourself

Titre = final reading – initial reading

Titre =

Titre =



Initial reading:_____ Final reading:_____

Figure 1.10 Calculating a titre volume from burette readings (Example 2)

Part 2: Using a burette

1. Measure 100 mL of 0.1 mol L^{-1} sodium hydroxide solution into a clean beaker.
2. Use a clamp to secure the burette. Always keep a beaker or conical flask under the tip of the burette in case the tap is not fully closed when you fill the burette.
3. Making sure the tap of the burette is closed, add approximately 5 mL of the sodium hydroxide solution from the beaker to the burette using a funnel.
4. Open the burette tap to drain this solution into a waste beaker.
5. Make sure the burette's tap is shut. Using a funnel, add the 0.1 mol L^{-1} sodium hydroxide solution to the burette, getting close to the 0.00 mL marking line.
6. To eliminate any bubbles in the burette tip, allow several drops of the solution to rinse through.
7. Slowly release the solution and try to get as close to 0.00 mL as possible.
8. Record the scale reading from the burette. Be as precise as possible by using two decimal places. This is your initial scale reading.
   NOTE: For practising purposes, 0.00 mL has been chosen, but it is not necessary to start a titration at 0.00 mL if your initial reading is accurate.

Part 3: Using a pipette

1. Rinse the pipette using a small amount of the 0.1 mol L^{-1} hydrochloric acid by drawing the solution up above the volume mark of the pipette.
2. Pour this into another waste beaker.

continued …

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3. Collect some fresh hydrochloric acid, again drawing the solution up above the volume mark of the pipette.
4. Carefully release the hydrochloric acid from the pipette until the bottom of the curve of the meniscus sits just on top of the volume mark.
5. Pipette the 20 mL hydrochloric acid solution into a conical flask.

Part 4: Performing a titration

1. Add two or three drops of phenolphthalein to the hydrochloric acid solution in the flask.
2. Place the volumetric flask on the white tile under the burette.
3. Open the tap and start releasing the sodium hydroxide solution into the flask.
4. If working in pairs, one person can gently swirl the flask and the other can control the release of the solution from the burette.
5. Once the colour pink starts to appear, start adding the sodium hydroxide solution drop by drop and keep swirling the volumetric flask.
6. Once the solution maintains a constant pink colour, close off the tap. This is called the end point. It is worth noting that the lighter the shade of pink, the more accurate your titration, as shown in Figure 1.11.

Figure 1.11 Example of titration set-up for Part 4 of this experiment, with pink phenolphthalein indicating that end point is reached

7. Record the final reading from the burette to calculate the volume of hydrochloric acid solution that has been added.
8. Repeat for another two trials.
9. Record the volume of sodium hydroxide solution for these trials to then calculate the mean volume. The table below can be used.

	Repeated trials			
	Trial 1	**Trial 2**	**Trial 3**	**Mean**
Initial reading from burette (mL)				
Final reading from burette (mL)				
Titre (final reading – initial reading) (mL)				

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Data loggers and probes

A data logger is an electronic measuring tool that accurately records data over time. It features a built-in instrument, such as a probe or sensor, that can measure a physical stimulus such as temperature, light, pressure, humidity or pH. The device is connected to a computer and converts the stimulus into a readout on the screen. This means the experimenter does not have to manually take a reading at set intervals, as the data logger takes very frequent (almost continuous) readings over time.

The benefits of using a data logger in scientific experiments include:

- highly accurate measurements
- an automated process that can be programmed and left to take readings regularly over a long period of time (e.g. overnight) or many readings over a very short period of time
- removal of the risk of personal error or miscalculations in interpreting a measurement scale and recording data.

The data collected from the experiment can be processed by specialised software or placed into a spreadsheet to allow for further analysis at a later point. This allows scientists to easily generate tables of values and graphs.

Figure 1.12 Weather stations are systems that measure and record weather conditions such as temperature, humidity, wind speed and direction, and precipitation. They typically consist of a variety of sensors and instruments that are connected to a data logger, which collects and stores the data.

Step 6. Manage risks and ethical considerations

In any experimental procedure, it is the job of the experimenter to eliminate any risks associated with the experiment. If elimination is not possible, then safe practices must be followed to protect experimenters. Equipment and materials should be assessed for risk prior to undertaking an experiment.

When assessing any risk, two key factors are considered:

- the likelihood of a hazard occurring
- potential level of harm that might result from it.

Experiments often involve hazardous chemicals that could cause injury or illness, making it essential to take appropriate precautions. Personal protective equipment (PPE) plays a crucial role in minimising these risks. PPE, such as gloves, safety glasses and lab coats, should be worn to protect the experimenter from exposure to harmful substances.

A safety data sheet (SDS) should always accompany any experiment involving hazardous materials. An SDS provides teachers and students with essential information about the health risks and safety measures related to hazardous substances, including chemicals. It outlines necessary precautions, first-aid measures, and details on safe handling and storage.

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Throughout this textbook, practical and investigative tasks have been evaluated for their level of risk to the experimenter. When planning these experiments, consider any chemical or biological hazards that have been mitigated in the experimental design and the low-level hazards that may still be present. The SDS offers detailed guidance on how to safely use a substance during and after the experiment, including associated health risks and waste disposal procedures.

Figure 1.13 Personal protective equipment is an important part of risk management.

Quick check 1.2

1. **Recall** what SDS stands for.
2. **Explain** why SDSs are essential within the science classroom.

Ethical implications of scientific investigation

ethics
the standards used to appraise and guide what is considered as acceptable conduct

When conducting scientific experimentation or investigation, it is important to note possible ethical implications and guidelines, particularly when working with animals and humans. **Ethics** refers to the principles and standards upheld by scientists that guide them in undertaking acceptable and appropriate conduct during experiments.

Animal testing

Scientists have ethical, social and legal responsibilities when working with animals in scientific investigations. In Australia, scientists must comply with the animal welfare laws in their state or territory. These laws generally require that any experimentation on animals must be humane and should consider alternatives such as replacing animals with a mathematical simulation, artificial model or a non-sentient species. Social issues may arise when scientists conduct experiments using animals without disclosing to the public the nature of their work as, naturally, humans are concerned for the safety of animal test subjects. Hence, ethics approval is required before any animal testing. Scientists generally follow the three Rs of animal ethics:

- *Replace* animals with non-animal alternatives or non-sentient beings.
- *Reduce* the number of animals used.
- *Refine* the techniques used such that experimentation is humane.

Figure 1.14 Wistar rats are a breed of laboratory rats that are widely studied because they have a consistent genetic make-up and are easy to look after. They have a docile and friendly temperament, making them easy to handle and work with. Wistar rats have been used in a wide range of scientific studies, including research on cancer, neuroscience and drug development, and have contributed greatly to our understanding of various biological processes.

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Human participants

While animal test subjects can provide useful data to scientists, scientific studies are often conducted to understand and influence human life. Thus, sometimes scientists need to progress their investigation to human participants, often called 'human trials'. In fields such as psychology and medicine, using people as participants is a critical source of data in experiments. Before beginning any research involving humans, investigators must submit a research plan to an ethics committee for discussion and approval. This ensures that the participants' physical and psychological welfare is considered by a team of medical and non-medical professionals. Any participants must be voluntarily involved in the research, give **informed consent** and not be harmed by their involvement. All data must be kept **confidential**, and all participants should have the **right to withdraw** at any point for any reason and to ask to have their data removed from the experiment.

School science experiments using human participants must be approved by the teacher and must adhere to the same ethical principles, including privacy considerations.

informed consent where possible, participants are informed about the risks and procedures involved in an experiment, and they sign to say they agree to participate

confidentiality participants' data and results must be kept private

right to withdraw the right for a participant to leave a study at any time for any reason

cultural appropriation use of cultural knowledge or tradition without acknowledgement or consent

implicit bias when someone's personal opinions influence their judgment without them being aware of it

Explore! 1.1

Ethics of working with Aboriginal and Torres Strait Islander Peoples

Collaborating with Aboriginal and Torres Strait Islander people on scientific investigations or to explore knowledge of Country can raise ethical issues for scientists. It is important that scientists avoid **cultural appropriation** and exploitation of First Nations Australian traditional knowledge. In the context of collaboration, scientists should critically analyse scientific sources and their own reports for **implicit bias** or racist ideas and seek multiple sources of information. Aboriginal and Torres Strait Islander people should be consulted and involved in any research involving their community, culture, traditional knowledge or Country. Moreover, it is important that any First Nations Australian artefacts discovered during fieldwork are left undisturbed. The scientist should contact the appropriate government agency and local Indigenous community leaders about the finding.

In 2020, a Rio Tinto mining blast destroyed the ancient Juukan Gorge rock shelter in Western Australia, against the wishes of the Traditional Owners. Excavations in 2014 revealed 47 000 years of Aboriginal presence, including tools, animal remains, and a human hair plait, making Juukan Gorge one of the oldest inland settlement sites in Australia. Amid global condemnation, the destruction highlighted flaws in heritage protection laws. Recent re-excavations continue to uncover significant artefacts, shedding light on the rich cultural history of the region.

Figure 1.15 It is important to report the discovery of any Aboriginal and Torres Strait Islander artefacts without moving or disturbing the artefact.

Use the internet to answer the following questions.

1. What is cultural appropriation and exploitation?
2. How might cultural bias be present in scientific literature?
3. How can cultural respect and sensitivity be demonstrated?
4. What does community engagement and data ownership and control mean in the context of working with Aboriginal and Torres Strait Islander people?
5. What is the purpose of the Aboriginal Cultural Heritage Committee of the Western Australia Government?

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Quick check 1.3

1. **Recall** some examples of protective equipment that researchers might use when handling hazardous materials in experiments.
2. **State** some ethical considerations that researchers must make when conducting experiments involving animals.
3. **Define** the term 'informed consent'.
4. **Define** the term 'right to withdraw'.

Step 7. Collect data

simulation
a computer program that uses a model to replicate the behaviour of a system over time

model
a simplified representation of a real-world system or phenomenon used to understand, analyse or predict its behaviour

Conducting the investigation involves collecting the data and preparing it for analysis. The planned method must be followed and any variations must be recorded and included in the discussion. Confounding variables that are identified should be discussed. It is an ethical requirement in science that results, including outliers and problems, are recorded accurately. In a scientific investigation, data can be collected in a variety of ways. It can be collected from experiments conducted in a laboratory, from fieldwork or by using **simulations** and **models**. The terms 'simulation' and 'model' are closely related and are often used interchangeably, but there is a difference between the two:

- A model is a simplified representation of a real-world system or phenomenon that is used to understand, analyse or predict its behaviour.
- A simulation is a computer program that uses a model to replicate the behaviour of a system over time. A simulation allows researchers to study the behaviour of a system under different conditions or scenarios, without the need for real-world experimentation, which can be time-consuming, expensive or even dangerous.

Supercomputers

Supercomputers can also be used to analyse massive amounts of data produced in experimentation, particularly when the experiments use data-logging machines. Supercomputers are extremely powerful computers capable of storing, distributing and analysing data for scientists. For example, at the Large Hadron Collider (LHC), data collected when particles collide is transmitted to the Worldwide LHC Computing Grid (WLCG). The data is sorted, filtered to remove background noise and then analysed for the scientists. This occurs millions of times per second, and the superfast grid and algorithms allow the massive amount of information to be useable by scientists in an appropriate timeframe.

Figure 1.16 The Large Hadron Collider sends data to a superfast computer grid to sort and analyse for scientists.

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Section 1.2 review

Online quiz

Section questions

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Section 1.2 questions

Remembering

1. **Define** the term 'titration' and explain its purpose in a laboratory setting.
2. **List** three pieces of specialised equipment commonly used in titrations.
3. **Identify** the key benefits of using a data logger in scientific experiments.

Understanding

4. **Describe** the difference between a model and a simulation in the context of scientific data collection.
5. **Summarise** the ethical considerations researchers must take into account when conducting experiments involving animals and humans.

Applying

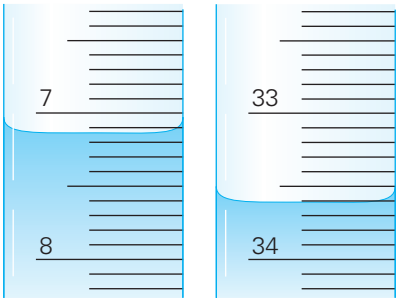
6. **Demonstrate** how to calculate the titre in a titration procedure using a burette.
7. **Describe** how data loggers can enhance the accuracy of experimental measurements in a laboratory setting.

Analysing

8. **Analyse** the potential risks associated with conducting an experiment using hazardous chemicals and propose strategies to mitigate these risks.
9. **Examine** the ethical implications of cultural appropriation in scientific research involving Aboriginal and Torres Strait Islander knowledge.

Evaluating

10. **Evaluate** the effectiveness of using simulations for scientific investigations compared to traditional experimental methods.
11. **Critique** the ethical guidelines governing animal testing and suggest improvements to enhance the welfare of animal subjects in scientific research.
12. Take the readings from the burette shown to **determine** the overall titre volume.
    Initial reading: _____ Final reading: _____ Titre: _____



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1.3 Processing and analysing data

Learning goals

At the end of this section, I will be able to:

1. Calculate the mean, median and mode of a data set.
2. Describe the uncertainty of a measurement, using the correct notation.
3. Describe patterns and relationships in data.

mean
the average value, found by adding all values together and dividing by the number of values

outlier
an anomalous data value that does not seem to fit the rest of the data

median
the middle value in an ordered data set, or the average of the two middle values if the set has an even number of observations

mode
the most frequently occurring value in a data set

Step 8. Process and present the data

Measures of central tendency

Data can be processed using descriptive statistics to better communicate trends to other scientists. In descriptive statistics, we measure the centre or 'central tendency' of a data set by calculating several statistics that help summarise it.

- The **mean** is the most common measure of the centre, found by dividing the sum of values by the number of values. However, it can be skewed by **outliers**, which are extreme values.
- The **median** is another measure of centre, representing the value with an equal number of data points above and below it. It is more reliable than the mean when outliers are present.
- The **mode** is the most frequently occurring value in a data set.

Worked example 1.1 outlines how to calculate these measures of central tendency.

Worked example 1.1

Determining the mean, median and mode of a data set

A group of students want to find out how long it takes to boil 500 mL of water using a particular brand of kettle. They replace the water after every boil and repeat it 10 times. Their results in minutes are: 2, 4, 4, 3, 2, 2, 3, 2, 13, 4. Determine the mean, median and mode of the data set.

Working	Explanation
Calculating the mean	
$\frac{(2 + 4 + 4 + 3 + 2 + 2 + 3 + 2 + 13 + 4)}{10}$ = 3.9 minutes	To calculate the mean, we add the values collected. Then we divide it by the number of values collected. In this case, there are 10 values.
Determining the median	
2, 2, 2, 2, 3, 3, 4, 4, 4, 13	First, we need to order the values from smallest to largest.
2, 2, 2, 2, **3**, **3**, 4, 4, 4, 13	If there is an odd number of values, then we pick the middle number. In this case, there is an even number of values, so we must find the mean of the two middle numbers. Note that there is an even number of values on either side of the values in red: four on the left and four on the right.
$\frac{(3 + 3)}{2}$ = 3 minutes	In this case, because the middle numbers are the same, the median is simply 3. If the middle numbers were 3 and 5, then the median would be $\frac{(3 + 5)}{2}$ = 4 minutes.
Determining the mode	
2, 2, 2, 2, 3, 3, 4, 4, 4, 13	First, we need to order the values from smallest to largest.
2, **2**, **2**, **2**, 3, 3, 4, 4, 4, 13	We can now see that the most frequently occurring number is 2, so the mode is 2 minutes.

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Working with large data sets

Measures of central tendency become particularly important when working with large data sets. Such data sets can sometimes contain gigabytes or even petabytes of data (one petabyte of data is equivalent to taking over 4000 photos every day for your entire life!). These data sets can come in different forms, like numbers in a database, structured files or unstructured data such as texts, images and videos. Large data sets are important in many fields because they help us understand complex information, make better decisions and discover new trends and patterns that lead to improvements and innovations.

Table 1.3 highlights how data is collected and used across different fields.

Sector	How data is collected and used
Healthcare	Patient data is collected and analysed to enhance diagnostic accuracy, develop personalised treatment plans and inform healthcare policies, leading to improved patient outcomes.
Online platforms	Social media and e-commerce sites gather extensive user data and use algorithms to personalise content, improve user experiences and optimise marketing strategies based on user behaviour and preferences.
Climate science	Environmental monitors and satellites continuously collect data. These large data sets facilitate advanced studies in climate science.
Government	Public records maintained by government institutions provide vast data sets on demographics, health and economic conditions, which inform public policy-making, improve public services and monitor social trends.

Figure 1.17 Medical sensors continuously collect data.

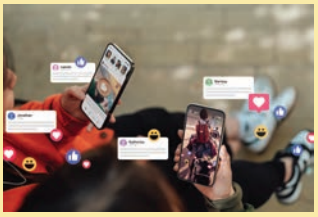

Figure 1.18 Algorithms process huge amounts of data to personalise the content being shown.

Figure 1.19 Weather stations continuously measure temperature, humidity, wind speed and air pressure to give real-time weather updates.

Figure 1.20 Birth, death and marriage registers stored in archive

Table 1.3 Data use and collection in different industries

continued …

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Sector	How data is collected and used
Business	Businesses use large data sets to streamline operations, optimise decision-making and enhance customer experiences, increasing efficiency and profitability. **Figure 1.21** Data is used to guide warehouse workers, helping them make informed decisions that improve operations by streamlining workflows and optimising inventory management.
Agriculture	Modern farming relies on data collected from various sources like satellite imagery, soil sensors and weather stations. This data helps farmers monitor crop health, optimise irrigation, manage pests and predict yields. **Figure 1.22** The Commonwealth Scientific and Industrial Research Organisation (CSIRO) provides data sets related to environmental science, agriculture and climate change. Some of CSIRO's research in Western Australia focuses on developing wheat and sorghum varieties that will be better adapted to future climate conditions. With rising temperatures, elevated CO_2 and drier conditions forecast for WA, the project aims to improve crop yield stability. By breeding new varieties and testing them under future climate scenarios, the research supports WA growers in managing climate challenges and ensuring long-term productivity.
Space exploration	In space exploration, data is gathered through satellites, telescopes and space probes. This data is used to study planetary systems, monitor cosmic phenomena and explore the potential for life beyond Earth. NASA EARTHDATA DATA PATHFINDERS Data Pathfinders guide you to finding, using, visualizing, and applying commonly used datasets and resources from across NASA's Earth science data collections. **Figure 1.23** NASA hosts extensive data sets on space exploration, earth sciences and atmospheric conditions.
Nuclear science	In nuclear science, data is collected from particle accelerators, nuclear reactors and radiation detectors. This data is used to study atomic interactions, develop nuclear energy technologies and ensure safety in nuclear facilities. **Figure 1.24** The Australian Nuclear Science and Technology Organisation (ANSTO) offers data sets on materials science, nuclear research and radiation. This includes data from the Open Pool Australian Light-water (OPAL) reactor, which is a key facility for nuclear experiments.

Table 1.3 *(continued)*

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Quick check 1.4

1. **Describe** a large data set.
2. **Provide** an example of how large data sets are used in a specific industry.

Science inquiry 1.1

Using data to validate scientific findings

Large data sets are important in **validating** scientific discoveries. For example, Gregor Mendel, known as the father of genetics, conducted experiments with pea plants. He carefully recorded the traits of thousands of plants, which helped him discover the laws of inheritance. By analysing his large sets of data, Mendel was able to confirm his genetic theories.

validating checking if something is accurate, correct or reliable

Similarly, the astronomer Vera Rubin studied how galaxies rotate. She used large amounts of data to show that galaxies were behaving in a way that couldn't be explained by visible matter alone. Her work provided strong evidence for the existence of dark matter, a groundbreaking discovery in astronomy.

Figure 1.25 Vera Rubin using a telescope in 1963

Figure 1.26 In climate science, huge amounts of data are collected from weather stations, satellites and ocean buoys. Scientists analyse this data statistically to create and validate models that predict climate change patterns.

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Try this 1.1

Using data to make decisions

In today's world, making informed decisions based on data is an essential skill, whether it involves managing resources, implementing new strategies or assessing the impact of changes. In groups, select an example below and work collaboratively to analyse the data, draw conclusions and make evidence-based decisions. As you explore your scenario, think critically about the potential outcomes of your decisions and the broader implications they may have.

Water usage in school:

- Gather and analyse water usage data in your school.
- Identify high-consumption areas.
- Propose water-saving strategies.
- Assess the implications of implementing these strategies.

School recycling program:

- Collect data on waste recycling versus landfill disposal.
- Evaluate the effectiveness of the current recycling program.
- Recommend improvements based on the data.
- Consider environmental and behavioural implications.

Study strategy effectiveness:

- Introduce a new study strategy
- Analyse pre- and post-implementation test scores.
- Determine if the study strategy improved performance.
- Decide if the strategy should be adopted schoolwide.
- Discuss the potential impact on student study habits.

Screen time versus academic performance:

- Survey screen time and collect academic performance data.
- Analyse the **correlation** between screen time and grades.
- Make recommendations on managing screen time.
- Consider the effects on health, wellbeing and academic outcomes.

correlation
the relationship between two variables

Tuck shop price change impact:

- Analyse tuck shop sales data before and after a price change.
- Identify trends in student purchasing behaviour.
- Make decisions about future pricing strategies.
- Evaluate the impact on student nutrition and tuck shop revenue.

Errors

Measurements are rarely perfect. The accuracy of any measurement will always be limited by the apparatus being used, the skills of the person collecting the data, the method being used and the environment where the experiment is being carried out. Whenever we do an experiment, we are attempting to determine the 'most true' data, but we will normally find variation in the results.

So, what are the possible reasons for the different values seen in our data? Mistakes are avoidable problems made by the person collecting the data, such as selecting the wrong piece of equipment or writing down results incorrectly. Although these are possible, a careful scientist should not make mistakes and would not include them in any report, unless they cannot be corrected by repeating the experiment.

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Errors are the difference between the results of experimental measurements and the true or reference values involved. They are not the same as mistakes.

Systematic errors arise from measured values that are either consistently larger or smaller than the true value of your data if equipment is used in the same way. Systematic errors can be minimised by careful experimental design, including calibrating measuring instruments correctly. Some examples are given below.

- Instrument effects are caused when a measuring instrument is faulty or has not been calibrated correctly. For example, if a scale used to measure a mass was not properly calibrated, so that all the readings were 3.00 grams greater than they should be, then all the measurements of mass would be consistently overestimated by 3.00 grams. This would lead to a systematic effect because the data is all wrong by the same amount each time a measurement is taken. A **zero calibration error** occurs when the initial value shown by a measuring instrument is not zero when it should be zero. For example, a scale may show 0.001 grams, even when nothing is being weighed.
- Environmental effects are caused by external factors such as temperature or humidity. For example, the measurements taken using a very long metal ruler such as a 10 m steel tape measure will differ depending on the temperature. In low temperatures the ruler will contract, whereas in warmer temperatures it will expand. This means that all the measurements taken under those particular conditions would always be lower or higher than the correct value.
- Observation errors are caused by undertaking the wrong observations, or reading instruments incorrectly. For example, a **parallax error** may occur when the observer's eye is positioned at an angle to the measurement markings, causing the data to be either larger or smaller than the correct value.

systematic error
an error that occurs through a poorly calibrated device (consistently high or consistently low)

zero calibration error
a measuring instrument giving a non-zero reading when the true value should be zero

parallax error
a measurement taken that is not the true value due to the position of the object along various lines of sight

random error
an error caused by limitations of the measurement device or the observer and does not follow a regular pattern

Even if careful experimental design removes systematic errors, **random errors** will remain that will affect the accuracy of a measurement. These are caused by limitations of the measurement device and the observer and are equally likely to be positive or negative because they do not follow a regular pattern. They can be caused by the experimenter's inability to obtain the same measurement in the same way to get the same result. You may measure the mass of a piece of magnesium ribbon three times using the same balance and produce slight variations in your results: for example, 1.36 g, 1.38 g and 1.39 g.

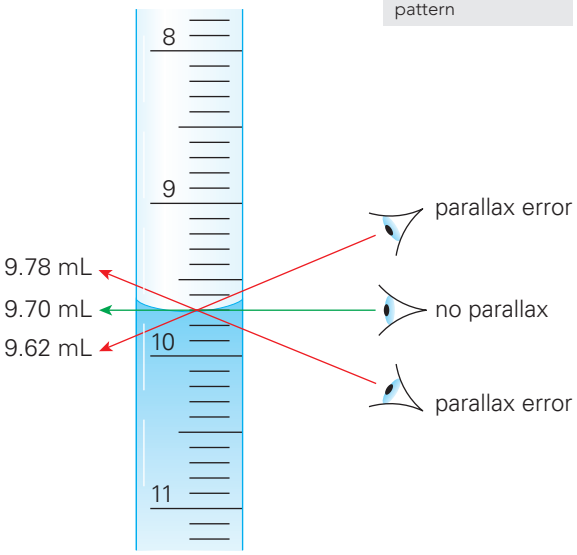

Figure 1.27 The position where there is no parallax is the correct eye level for reading the measurement.

Reading errors can also occur when a measurement falls between two measurement markers. An observer would have to estimate the true value, and this would differ between observers. It is likely that half of the results obtained would be estimates that are too large and half would be too small. These effects are an unavoidable part of doing experiments and can affect the precision of results, but the resulting error can be reduced by repeating the experiment many times and taking average values.

reading error
a reading or measurement that is not the true value

Uncertainty

Due to random and systematic errors in the experimental process, there will always be a margin of doubt about any of your results. But how big is this margin? We have looked at how random and systematic errors can arise, but we need to be able to quantify them. This happens through estimating the uncertainty of any measurement. This is an interval around a measured value which quantifies the likelihood that a repetition of our experiment will produce a new result that would lie within this interval.

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The notation for a measurement and its uncertainty should take the following format (remember to add the appropriate units):

measured value ± uncertainty

absolute uncertainty the size of the range of values within which the actual 'true value' of a measurement probably lies

where ± means 'give or take'. This tells us the **absolute uncertainty**.

The following rules are often used to determine the absolute uncertainty in a single measurement when using either an analogue scale or digital measuring instrument:

- The uncertainty in an analogue scale measuring instrument is equal to the smallest increment of the instrument divided by two.
- The uncertainty in a digital measuring instrument is equal to the smallest increment of the instrument.

However, if we take multiple measurements to calculate a mean, we can estimate the absolute uncertainty by calculating half the range, as shown in Worked example 1.2.

a **b**

Uncertainty = $\frac{1\text{ V}}{2}$ = 0.5 V Uncertainty = $\frac{100\text{ g}}{2}$ = 50 g Uncertainty = 0.1 V Uncertainty = 0.001 g

Figure 1.28 There are different rules for single measurements using **(a)** analogue or **(b)** digital measurements. Remember to include units!

Worked example 1.2

Calculating absolute uncertainty

A student measured the mass of a piece of magnesium ribbon three times and recorded the following values: 1.36 g, 1.38 g and 1.39 g. Calculate the absolute uncertainty.

Working	Explanation
Calculating the mean	
$\frac{1.36 + 1.38 + 1.39}{3}$ = 1.38 g	To calculate the mean, add the values collected. Then divide it by the number of values collected. In this case, there are three values.
Calculating the range	
1.39 – 1.36 = 0.03 g	To calculate the range, subtract the minimum value from the maximum value.
Calculating the uncertainty	
0.5 × 0.03 = 0.015 g	To calculate the uncertainty, take half the range. This can be rounded up to 0.02 g because this is the same number of decimal places as the measurements.
Mass = 1.38 ± 0.02 g	You can then include this uncertainty when communicating the results. The mass of the magnesium can therefore be expected to be between 1.36 and 1.40 grams.

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The uncertainty of any measured value can also be expressed as a percentage or as a ratio. This is **relative uncertainty**. This is calculated by dividing the absolute uncertainty of the result by the result itself, as shown in Worked example 1.3. The relative uncertainty can be more useful than the absolute uncertainty because it puts your experimental data into perspective. For example, if you made an error in measuring the length of your eraser, it would be more noticeable than if you made the same error when measuring the table. Relative uncertainties do not have units, unless the uncertainty is multiplied by 100, where it is reported as a percentage.

relative uncertainty the ratio of the absolute uncertainty and the reported value, often expressed as a percentage

Worked example 1.3

Calculating relative uncertainty

You measured the length of your table (80.0 cm) and your eraser (5.0 cm) using a metre ruler.

length of table = 80.0 cm ± 0.05 cm

length of eraser = 5.0 cm ± 0.05 cm

The absolute uncertainty of both measurements is ±0.05 cm. Calculate the relative uncertainty of both measurements.

Working	Explanation
Calculating the relative uncertainty	
Relative uncertainty of table length: $\frac{0.05}{80.0} = 0.000625$	To calculate the relative uncertainty, divide the absolute uncertainty of a value by the value.
Relative uncertainty of eraser length: $\frac{0.05}{5} = 0.01$	
Calculating the percentage uncertainty	
Percentage uncertainty of table length: $0.000625 \times 100 = 0.0625\%$	This can then be reported as a percentage by multiplying by 100. We can now see that the relative uncertainty of the eraser measurement is much higher than that of the table measurement.
Percentage uncertainty of eraser length: $0.01 \times 100 = 1\%$	

Worked example 1.3 illustrates the importance of considering both absolute and relative uncertainty when reporting measurement results. While the absolute uncertainty is the same for both the table and eraser measurements, the relative uncertainty is significantly higher for the eraser due to its smaller size.

Uncertainty when measuring length

When we measure length, we normally use a ruler or a tape measure. These are scale measuring instruments, so the uncertainty should be equal to half the smallest increment of the instrument. The smallest division of a ruler you probably have is one millimetre, producing an uncertainty of 0.5 mm or 0.05 cm.

If you were measuring the length of an eraser, you would place the eraser so it was aligned at zero on your ruler, so there is an additional ±0.05 cm error at that end. Therefore, the total error for a centimetre ruler is 0.05 cm + 0.05 cm = ±0.1 cm.

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Quick check 1.5

1. **State** the sort of uncertainty that each of the following scenarios represents.
   a) A measuring tool is incorrectly calibrated and regularly underestimates the mass.
   b) A measuring tool is not very precise and the temperatures vary by approximately 0.5°C in either direction.
2. **Describe** how the effect of random uncertainty can be reduced.

Which uncertainty should be recorded?

In most experiments, uncertainty can come from two main sources: the measuring equipment itself (instrument uncertainty) and the way the measurement is taken (measurement uncertainty). The largest source of uncertainty should be recorded because it most significantly affects the reliability and accuracy of your results.

Recording this largest source prevents you from arriving at misleading conclusions about how precise your results actually are.

Figure 1.29 Measurement tools vary in their precision.

Step 9. Describe patterns in the data

Data can be presented in tables, in graphs and using descriptive statistics to better communicate trends to other scientists. When you have graphed your data, you can determine if there are any patterns, trends or relationships. One important aspect to consider when analysing data is correlation, which is the relationship between variables in terms of their strength and direction. Correlation provides valuable insights into how changes in one variable relate to changes in another.

To investigate the correlation between variables, you can examine the scatter plot created from your data (see Figure 1.30). Remember that the independent variable should be plotted on the horizontal axis (or x-axis), and the dependent variable should be plotted on the vertical axis (or y-axis). By observing the pattern of the data points on the graph, you can make inferences about the relationship between the variables. When stating any relationship, it's important to follow the pattern of 'as the [independent variable] [state how it changes], the [dependent variable] [state how it changes]'. Additionally, it's essential to consider the direction and strength of the correlation.

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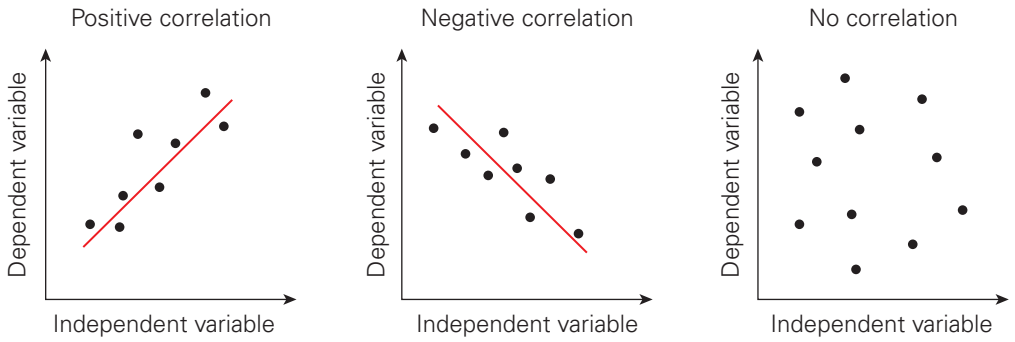

The points lie close to the line of best fit, which has a positive gradient. This shows that as the independent variable increases, the dependent variable increases.

The points lie close to the line of best fit, which has a negative gradient. This shows that as the independent variable increases, the dependent variable decreases.

There is no pattern in the results. There is no relationship between the independent and dependent variables.

Figure 1.30 Two variables may be related to each other positively or negatively, or they may have no correlation.

Section 1.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

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Section 1.3 questions

Remembering

1. **Define** the following terms: mean, mode, median, range.
2. **Recall** why large data sets are useful.
3. **State** what a trend is in a data set.
4. **Define** an outlier in a data set.

Understanding

5. **Describe** how systematic error differs from random error.

Applying

6. **Describe** the relationship in a data set that shows a positive correlation between hours studied and test scores.
7. **Calculate** the mass and absolute uncertainty of an object that you weigh three times and obtain values of 4.95 g, 5.00 g and 5.05 g.

Analysing

8. **Classify** the following errors as either random errors or systematic errors.
   a) Instrument error: A burette is leaking, so every reading taken is 0.1 mL lower than the actual value.
   b) Personal error: When recording the data, the researcher has a poor understanding of rounding decimals and consistently rounds them up to the nearest whole number.
   c) Instrument error: A set of scales is not very precise, and the displayed mass is often out by around 1–3 grams in either direction.

Evaluating

9. **Evaluate** the reliability of a measurement where a digital scale consistently reports a weight 0.02 grams higher than the known true weight of an object. What steps should be taken to improve measurement accuracy?

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1.4 Evaluating and communicating

WORKSHEET
Evaluating investigations

Learning goals

At the end of this section, I will be able to:

1. Evaluate and conclude the findings from an experiment.
2. Assess the validity and reproducibility of methods.
3. Evaluate the validity of conclusions and claims.

Step 10. Evaluate the method

The evaluation should critically discuss the reliability and validity of the experimental process. This involves assessing the quality of your data, identifying outliers and providing reasons for their appearance. Explain any issues with your results by considering the limitations imposed by the equipment and techniques used. Account for both random and systematic errors. Use your results to evaluate the accuracy of the data collected, which can be determined by examining whether the line of best fit aligns closely with your data. Also consider any outliers. Finally, suggest improvements and extensions logically derived from your data analysis.

When using primary data, it's important to evaluate both the validity and reproducibility of the methods in the investigation. Reproducibility means that other researchers should get the same results if they repeat the study. If different trials or researchers find different results, it raises questions about the reliability of the conclusions. Problems with the validity or reproducibility of the methods can lead to gaps or weaknesses in the conclusions drawn from the data. Therefore, it's crucial to evaluate these factors to ensure that the findings are trustworthy.

Assumptions made during the research process can affect the validity of the conclusions. For example, if a researcher assumes that a group of students in a study represents all students, but it does not, this can lead to biased conclusions. In a study on caffeine's effects on test scores, if the sample only includes students from a specific academic program, the findings may not reflect how caffeine affects students in general. If the researcher assumes that self-reported caffeine consumption is the most accurate method, that may introduce bias and compromise the conclusion's validity.

It's also essential to identify any unexamined facts in the research and evaluate their reasonableness. For instance, if a study assumes that caffeine greatly improves cognitive performance without considering other factors like prior knowledge or study habits, it could lead to flawed conclusions. Limited evidence to support the claim that caffeine enhances academic performance raises questions about the findings' reliability.

When assessing assumptions, consider areas of uncertainty to determine if there is enough evidence to support the conclusions or if other conclusions could be possible. By carefully evaluating the context and methods, researchers can avoid potential problems in their investigations.

Improving data quality can enhance both the reliability and validity of results. Specific strategies include increasing sample size, ensuring precise measurements and minimising errors. For example, in the caffeine and test score study, increasing the sample size to include a diverse group of students would provide a better understanding of caffeine's effects. Repeating measurements and calculating averages can help reduce the effects of random errors on the quality of the data.

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Using calibrated equipment and following standard procedures also improves data accuracy. For instance, if researchers measure caffeine consumption, using precise scales and standard serving sizes ensures consistent data collection. Additionally, controlling factors like study habits and sleep quality ensures that the observed effects are due to the independent variable being tested. By implementing these strategies, researchers can obtain more reliable data, leading to stronger conclusions that better reflect the true nature of the relationships studied.

Step 11. Write a conclusion

In the conclusion you should answer your original research question, stating whether your hypothesis is supported or not. You should start with a general statement that refers to your findings in a general way, but then justify this by using actual data from your results to support this statement. You can also use your own scientific knowledge to explain your results. The strength of a conclusion depends on the quality of the data collection and evaluation of trends through the scientific method. This is especially crucial when the investigation aims to support or refute a claim. To ensure an insightful conclusion, the experiment must be thoroughly planned and executed with a focus on gathering reliable and valid evidence.

Making claims

Making a claim prior to or after conducting a scientific investigation must be considered very carefully. The work of scientists is reviewed by other scientists in their field of expertise (the peer review process of accepting research reports for publication), so it is imperative that any claim made is supported by reasonable evidence. Scientists first conduct literature reviews from a wide range of secondary sources and select reliable data and results which have already been supported by evidence and peer-reviewed in the past. These details improve the credibility of the source and therefore improve the credibility of their own experimental work. In their literature review, scientists may refute claims from other secondary sources, including media reports, if there is not sufficient evidence to fully support the claims. When making claims, scientists select data appropriate to the audience with which they are communicating. Often the audience targeted may be those who could be providing funding for the research, and due to competition between scientists, the claims made must be supported by evidence.

Figure 1.31 A science research team meets to discuss their conclusions and claims.

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Practical 1.2

Comparing the effect of indigestion remedies

Background

The stomach is an essential organ involved in the digestion of food. It achieves this by creating a highly acidic environment (pH of approximately 2 to 3) through the production of hydrochloric acid. However, an excess of acid in the stomach can cause painful indigestion.

Antacids are a common treatment option as they are alkaline and neutralise excess stomach acid. Now that you have the skills to measure volume accurately, design an experiment that will compare three different antacids (A, B and C) to determine which is most effective in neutralising acidity.

Materials

- hydrochloric acid (1 mol L^{-1})
- 3 different antacids
- titration equipment
- electronic balance
- spatula
- Congo red indicator
- watchglass

Method

Design the method. Plan your experiment with a lab partner, taking into consideration:

- your research question
- the independent variable and dependent variables
- the variables that will be controlled in this experiment
- how you will document the results, including the results table, graph and analysis of the trends.

Carry out the experiment and form your conclusion. Consider how you could improve the accuracy of your results in the future.

Step 12. Write a reference list

When incorporating information from external sources into your work, you must acknowledge the original authors. This acknowledgement is achieved using a recognised referencing style. Referencing serves a dual purpose: it indicates the quality of your information and allows others to trace back to the sources you have used.

There are various referencing styles available, each with its own conventions. One widely used style is the APA (American Psychological Association) format. In APA style, when you mention a source in your writing, you should include the author's last name and the publication year in parentheses right after the reference. For instance, if you were discussing a study conducted by Reid and Dale in 2020, you would write, 'as shown in the research (Reid and Dale, 2020)'. At the end of your document, you must compile a reference list that includes detailed information for each source you cited. This list should feature the author's name, the title of the work and the publication details that can help others locate the source.

plagiarism the act of using another person's ideas, research or creative works without proper attribution, presenting them as your own

Proper referencing is important for several reasons. Firstly, it helps you avoid **plagiarism**, which is the unethical practice of presenting someone else's ideas or work as your own. By clearly crediting the original authors, you demonstrate academic integrity and respect for intellectual property. Secondly, referencing enables your readers to verify your sources and assess the reliability of the information you have provided. This transparency is crucial in academic writing, where the credibility of your work relies on the quality of the sources you utilise.

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Communication

Effective science communication is essential in today's world, where understanding scientific concepts and findings is necessary for informed decision-making. Science communication involves presenting complex ideas and data clearly and accurately, ensuring that your message is both accessible and engaging to your audience. Whether you are explaining a new scientific theory, detailing the results of an experiment or constructing a persuasive argument, it is important to communicate effectively.

Figure 1.32 Scientists present their findings at a conference

When doing scientific research, it's important to gather and use information from many different places. This can include reading texts, looking at diagrams and flow charts, studying tables, databases, graphs and even watching videos or using interactive tools. For example, if you're studying how pollution affects a local ecosystem, you might need to gather data from scientific articles, environmental reports and databases. Diagrams can help you understand processes, while tables and graphs can show important numbers and trends. Videos and other multimedia resources can provide extra information and context.

Once you have all this information, the next step is to combine it to make a strong argument. This means looking for patterns, common ideas and linking everything together to support or challenge an idea. For example, if several studies show that pollution harms marine life, you can use this combined information to argue for better pollution control measures. Being able to find, understand and put together information from different sources is important for understanding your research topic and making evidence-based conclusions.

When presenting your scientific arguments, you should use evidence and correct scientific language. Your evidence is the data that you collected through your investigation and is used to support your claims. For instance, if you are explaining how plants grow faster with more sunlight, you should provide data from experiments and use terms like 'photosynthesis', 'hypothesis' and 'variables'.

Tailoring your language to your audience – whether they are classmates, teachers or the general public – is also something that needs to be considered. For a scientific audience, detailed and technical language is appropriate, while a more general audience might require simpler explanations.

Making thinking visible 1.1

Think, pair, share: Evaluating research methods

Consider the following question: What key elements should be evaluated to assess the validity of a scientific method?

1. **Think**: Individually list key elements to consider when evaluating an experiment's validity (e.g. sample size, control of variables).
2. **Pair**: Share your list with a partner and discuss. Combine your thoughts into a single summary.
3. **Share**: Present your combined list to another pair or group. Listen to their contributions and add any new ideas to your list.

The *Think, pair, share* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Explore! 1.3

Persuasive texts

Scientific texts often aim to persuade readers to adopt a specific perspective. Authors do this by presenting strong evidence and using authoritative language. Recognising this can help you critically analyse scientific literature. In the early twentieth century, several scientific articles and adverts were published to persuade readers that smoking cigarettes had health benefits. The authors used authoritative language, referring to 'studies' and 'clinical trials' that supposedly showed positive effects of smoking.

However, these studies were funded by tobacco companies, and the authors positioned themselves as experts by using medical terminology and referencing doctors who endorsed smoking.

As a reader, you should identify the perspective and consider any potential biases. In this case, the funding from tobacco companies likely influenced the research and its presentation.

Over time, further research has conclusively showed the severe health risks associated with smoking, including lung cancer and heart disease, disproving the earlier claims.

"We know our Luckies
That's how we stay slender"
EVERY woman who fears overweight finds keen interest in new-day and common-sense ways to keep a slender, fashionable figure. Overweight must be avoided. "Better to light a Lucky whenever you crave fattening sweets."
Toasting does it. Toasting develops and improves the flavor of the world's finest tobaccos. Lucky Strike satisfies the longing for things that make you fat, without interfering with a normal appetite for healthful foods. That's why Luckies are good to smoke. Toasting makes Lucky Strike the healthy cigarette for you to smoke.
Many men who carefully watch their health discovered this years ago. They know that Luckies steady their nerves and do not slow up their physical vigor—prominent athletes have gone on record that this is so. They know that 20,679 physicians have stated that Luckies are less irritating to the throat than other cigarettes.
A reasonable proportion of sugar in the diet is recommended, but the authorities are overwhelming that too many fattening sweets are harmful and that too many such are eaten by the American people. So, for moderation's sake we says—
"REACH FOR A LUCKY INSTEAD OF A SWEET."
The Misses Catherine Moylan, Myrna Darby, Married Finley, now appearing in Ziegfeld's "Whoopee"
LUCKY STRIKE
"IT'S TOASTED"
CIGARETTES
Reach for a Lucky instead of a sweet.
"It's toasted"
No Throat Irritation—No Cough.

Figure 1.33 Some cigarette advertisements suggested smoking could aid in weight loss.

SMOKING CAUSES PERIPHERAL VASCULAR DISEASE
WARNING
The toxic chemicals in tobacco smoke can be found in your breath, urine and blood when you smoke.

Figure 1.34 In Australia, all tobacco products sold are required by law to include health warnings on the packaging, including large images. In 2023, legislation was updated to include restrictions on more products, including e-cigarettes.

Quick check 1.6

1. **Describe** what might happen if scientific concepts are not communicated clearly.
2. **Explain** the role that evidence plays in scientific arguments.
3. **Describe** how you can check if your science communication is effective.

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Did you know? 1.2

Indigenous apps

Science communication is evolving, embracing diverse forms to reach broader audiences and engage people in more meaningful ways. Traditional methods, such as academic papers and lectures, are now supplemented by innovative approaches, including interactive digital tools, social media and culturally relevant storytelling. The Mamutjitji Story app, developed by Indigenous communities in WA's northern Goldfields, is an innovative tool designed to preserve the Ngalia language and traditional cultural knowledge. Using a Dreamtime story about the life cycle of the antlion, the bilingual app teaches both Aboriginal and Western science concepts. Ngalia, a language with only three remaining speakers, is at risk of being lost. However, through this app, the language is digitised and introduced to younger generations.

Co-writer Kado Muir, one of the last speakers of Ngalia, collaborated with his brother Talbot on the project, building on their family's efforts to preserve the language. The app is seen as a step towards connecting young people with their cultural heritage while helping them navigate both Indigenous and Western cultures. Muir also sees the app as a way to inspire other Indigenous groups worldwide to use technology to maintain their cultures. By blending Traditional Knowledge with modern technology, the app fosters a sense of belonging and strengthens students' understanding of their environment.

Figure 1.35 Kado Muir is the co-writer of the Mamutjitji Story app and one of only three speakers of Ngalia.

Section 1.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 1.4 questions

Remembering

1. **Recall** what reproducibility means in research.

Understanding

2. **Explain** why it is important to evaluate the validity of data.
3. **Explain** why using various sources of information is important in scientific research.

Applying

4. If a researcher uses an inappropriate method for data collection, **identify** how this would this affect the research findings.
5. **Identify** how diagrams and graphs can be used to support a scientific argument.

Analysing

6. **Analyse** the potential effects of using outdated secondary data on the validity of a research study. What problems might arise from using such data?
7. **Analyse** how biases in scientific studies might influence the interpretation of results.

Evaluating

8. **Evaluate** the effect of increasing sample size on the validity of data.

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Extension practical

Titration using a pH probe

Be careful
Wear appropriate personal protective equipment.

Aim

To complete a titration using a pH probe linked up to a data-logging program to produce a graph showing pH changes as a base is added to an acid.

Materials

- 0.1 mol L^{-1} hydrochloric acid (strong acid)
- 0.1 mol L^{-1} sodium hydroxide (strong base)
- 0.1 mol L^{-1} acetic acid (weak acid)
- 0.1 mol L^{-1} sodium carbonate (weak base)
- pipette
- burette
- burette funnel
- conical flask
- beakers
- retort stand
- burette clamp
- pipette bulb
- bosshead × 2
- clamp × 2
- wash bottle
- pH probe and data logger
- computer or laptop
- data-logging software

Method

You will be provided with four different combinations of acid and base solutions to titrate. The steps below should be repeated for each of the four combinations. Decide who will continuously swirl the solution in the beaker and who will release the base into the beaker using the burette.

1. Set up the burette and apparatus as shown in Figure 1.36 by using a clamp and a retort stand to secure the pH sensor.

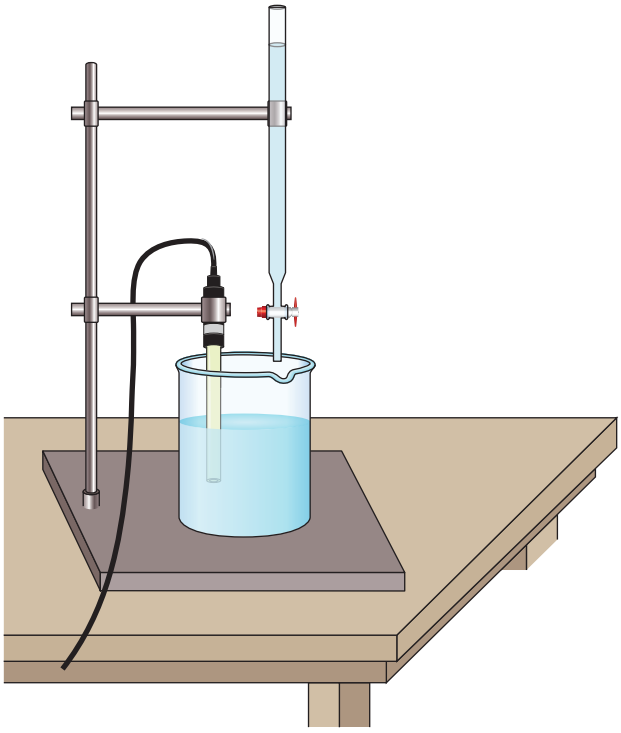

Figure 1.36 Experimental set-up

continued …

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2. Rinse the burette thoroughly with a few millilitres of the basic solution.
3. Fill the burette using approximately 50 mL of the basic solution and record the precise volume.
4. Add 50 mL of distilled water to a 250 mL beaker.
5. Pipette 10 mL of the acid into the beaker of distilled water.
6. Connect the data logger and pH sensor to the computer or laptop and open up the relevant 'Acid Base' titration program.
7. Monitor the pH for approximately 20 seconds and wait for the reading to stabilise.
8. Enter 0 mL as the first data point of base added in the computer program.
9. Slowly start to add some of the basic solution until the pH has risen approximately 0.2 units.
10. Wait for a stable pH reading and record the burette reading (volume of base left in the burette) to the nearest 0.01 mL.
11. Repeat steps 9 and 10 until the pH starts to get close to 3.5.
12. Start adding smaller equal volumes of approximately 0.1 mL of basic solution to the beaker, making sure to record the burette reading into the software after each increment.
13. When the pH reaches close to 10, add larger amounts of basic solution that raise the pH by approximately 0.2 units.
14. Continue adding the basic solution until the pH remains constant and stable.
15. Click 'stop' on the software and save copies of the table and graph.
16. Dispose of the beaker contents as directed by your teacher and the safety data sheet.

Results

Print out your table and graph.

Discussion

1. Compare the four different graphs you have produced.
2. Discuss the different shapes of curves that were produced in relation to the strength of the acid and base combinations used. Compare them to Figure 1.37, which represents a standard titration graph of the kind that would be found in a literature review.
3. Discuss whether this experiment would have been possible without the use of a data logger.
4. Propose any extensions or improvements that could be made to this experiment if you were to do it again.

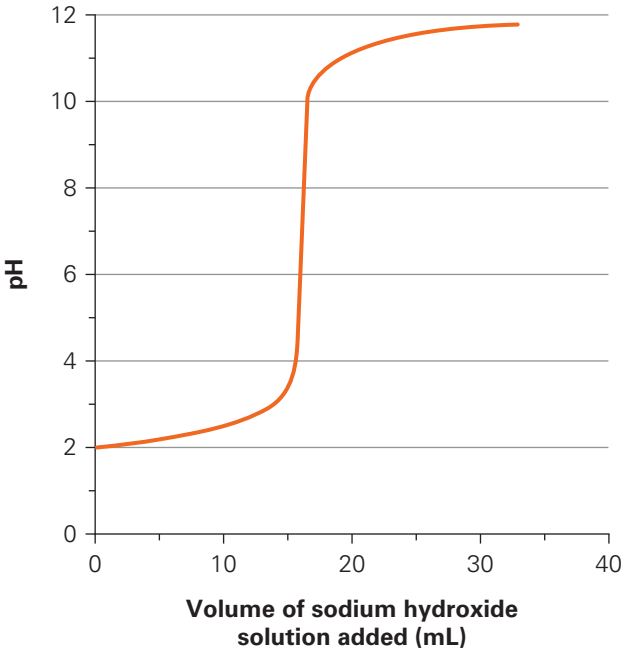

Figure 1.37 A graph showing how the pH changes as a volume of sodium hydroxide (a strong base) is titrated into a strong acid

Conclusion

1. Make a claim regarding the pH when a base is titrated into an acid based on this experiment.
2. Support the statement using the data you gathered.
3. Explain how the data supports your statement.

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Chapter review

Chapter checklist

Success criteria		Linked questions
1.1	I can propose investigable questions.	13a
1.1	I can distinguish independent, dependent and controlled variables in a scientific investigation.	2, 8, 12a, 14b
1.1	I can write an appropriate scientific hypothesis.	14a
1.1	I can differentiate between reliability, replicability and reproducibility.	4
1.2	I can select and use of specialised scientific equipment such as titration equipment and data loggers.	7
1.2	I can describe the use of models and simulations.	9
1.2	I can identify and manage risks and ethical issues in an experiment.	3, 5, 14e
1.3	I can calculate the mean, median and mode of a data set.	12d
1.3	I can describe the uncertainty of a measurement, using the correct notation.	11
1.3	I can describe patterns and relationships in data.	data questions
1.4	I can evaluate and conclude the findings from an experiment.	14c
1.4	I can assess the validity and reproducibility of methods.	14d
1.4	I can evaluate the validity of conclusions and claims.	13a, 14d

Go online to access the interactive chapter review

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Recall** what a scientist should do if they discover an Aboriginal and Torres Straight Islander artefact during fieldwork.
2. **Define** the following terms.
   a) independent variable
   b) dependent variable
   c) controlled variables
3. **Recall** the reason a safety data sheet (SDS) should be understood before conducting an experiment.

Understanding

4. **Define** the following terms.
   a) reliability
   b) reproducibility
   c) replicability
5. **Describe** why it is necessary to complete a risk assessment before conducting the experiment.

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6. **Explain** why repeating an experiment multiple times is considered a method to minimise random errors.
7. **Describe** why a burette is used in an experiment.

Applying

8. Read the following text.

   Research has been conducted on the effect of short, daily exercise on mice and rats. The mice and rats were all exercised mildly for 10 minutes once a day. When the mice and rats exercise, it was shown that they develop more new brain cells, compared to if they do not exercise. These new cells were mostly located in or around the hippocampus, which is involved in the creation and storage of memory, improving their memory and learning abilities when tested.

   Source: 'Even a 10-Minute Walk May Be Good for the Brain', Gretchen Reynolds, *The New York Times*, 24 October 2018.

   Using the information, **categorise** the following variables as independent, dependent or controlled.

   a) memory ability
   b) exercise intensity
   c) age of rodent
   d) undertaking exercise
   e) time taken to exercise

9. Read the following text.

   A simulation was used to model the spread of a disease in a city of 10000 people. The simulation assumed that only 60% of people followed social distancing guidelines.

   a) **Explain** one advantage and one limitation of using a simulation instead of a real-world experiment.
   b) **Suggest** a way to improve the accuracy of the simulation results.

Analysing

10. **Distinguish** between accuracy and precision.
11. **Contrast** relative and absolute uncertainty.
12. The table below shows the effect of changing the pH of a pond on the number of tadpoles in the pond.

pH of water	Number of tadpoles		
	Trial pond 1	Trial pond 2	Trial pond 3
8	45	44	43
7.5	69	71	70
7	78	80	81
6.5	88	85	89
6	43	43	43
5.5	23	24	5

   a) **Identify** the independent variable and dependent variable of this study.
   b) **Identify** the optimum pH for tadpole growth.
   c) **Identify** an outlier in the data.
   d) **Calculate** the mean and median number of tadpoles in a pond with a pH of 7.5.
   e) **Calculate** the range of the number of tadpoles in a pond with a pH of 6.5.
   f) **Construct** a graph of the number of tadpoles in trial pond 1 against the pH of water. **Suggest** appropriate labels for the axes and title and add them to the graph.

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Evaluating

13. A student conducted an experiment to measure the rate of photosynthesis in pond weed at different light intensities. They concluded that 'increased light always increases the rate of photosynthesis'.

- **a)** **Evaluate** the validity of this conclusion.
- **b)** **Suggest** how reproducibility of the experiment could be tested.
- **c)** **Assess** how reliable their results would be if they only conducted the test once at each light level.

14. A year 10 student was interested in testing the effects of sleep deprivation on memory recall in secondary school students. He chose four of his year-10 male friends to be the participants. Two of them said they went without sleep for 24 hours and were then given 20 three-letter nonsense words (e.g. tuf, pud, wes) to memorise for two minutes and then recall. The other two of his friends said they slept for their usual time and were given the same memory test: 20 three-letter nonsense words to memorise for two minutes and then recall. Results are shown below.

	Mean recall score of three-letter nonsense words (out of 20)
Sleep-deprived group	5
Non-sleep-deprived group	11

- **a)** **Propose** an investigable question and a hypothesis for this experiment.
- **b)** **List** the independent variable, dependent variable and two possible controlled variables in the experiment.
- **c)** **Propose** a conclusion that can be drawn from the results obtained.
- **d)** **Evaluate** the possible limitations affecting the reliability and validity of this experiment.
- **e)** **Discuss** the ethics of this study and potential harm to the participants involved.

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Data questions

High school students were analysing the content of ethanoic acid in a commercial vinegar sample and had made up a dilute solution of 0.1 mol L^{-1} ethanoic acid based on the concentration of ethanoic acid given on the bottle of vinegar. The students set up a titration with 20.00 mL of their ethanoic acid in a conical flask (via pipette) and filled a burette with 0.1 mol L^{-1} NaOH.

If the ethanoic acid content quoted on the vinegar bottle was correct, the students hypothesised that 'if 20 mL of 0.1 mol L^{-1} ethanoic acid is present, then 20 mL of 0.1 mol L^{-1} NaOH will be required to reach an end point'. The titration data from two students carrying out six replicated trials are shown in Table 1.4.

Titration	Volume (mL) 0.1 mol L^{-1} NaOH to end point	
	Student 1	Student 2
1	19.95	20.50
2	20.00	20.50
3	20.50	20.50
4	22.70	29.30
5	19.95	20.40
6	20.00	20.40
Mean		

Table 1.4 Titrations of ethanoic acid and sodium hydroxide

1. **Identify** and circle any outliers in each student's trials.
2. **Calculate** the mean volume of NaOH required to reach the titration end point, after removing outliers for each student.
3. The 'true' value for the titration given the actual concentration of ethanoic acid should have been 20.00 mL of 0.1 mol L^{-1} NaOH. **Interpret** the validity of this experiment in identifying the concentration of ethanoic acid.
4. **Identify** if any patterns occur in the results obtained by the students.
5. **Contrast** the data in Table 1.4. Was each student accurate?
6. **Analyse** the data in Table 1.4. Were the students precise?
7. **Justify** whether the data presented by students 1 and 2 provide evidence to support the hypothesis.
8. **Compare** the data fluctuations for each student. Do the data points fluctuate randomly above and below the true value or are they biased in one direction?
9. Based on the data presented, **infer** whether the experiment was repeatable and reproducible.

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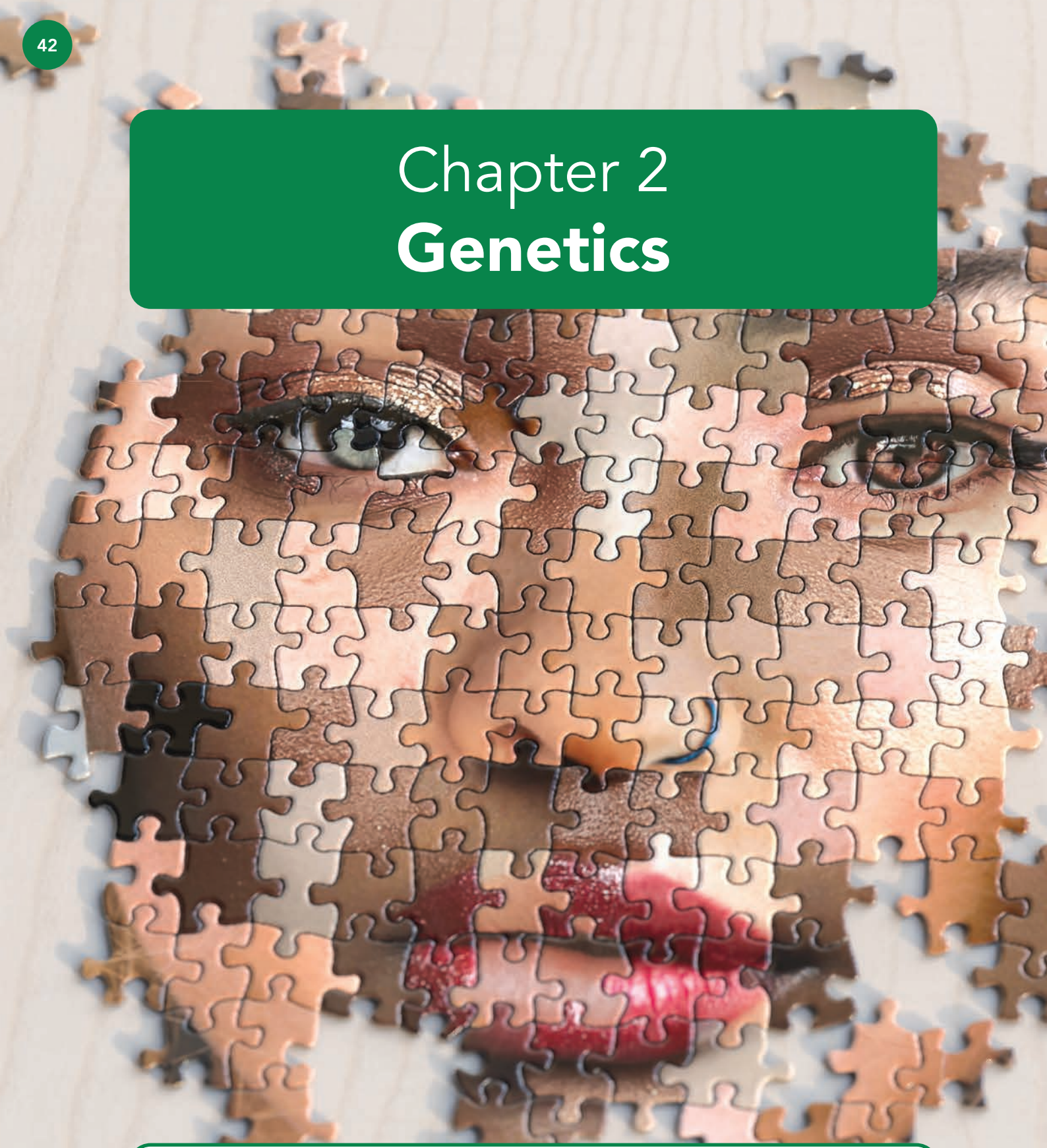
Chapter 2
Genetics



Chapter introduction

Everyone is unique, but you may look similar to your parents. This is thanks to the genes that they passed on to you. Genes carry the information that determines your traits and are made of DNA. This chapter explores the structure and function of DNA and genes in heredity. You will consider how variation is increased in offspring and predict patterns of inheritance. You will also examine what happens when there are problems with DNA and how these may be caused by the environment.

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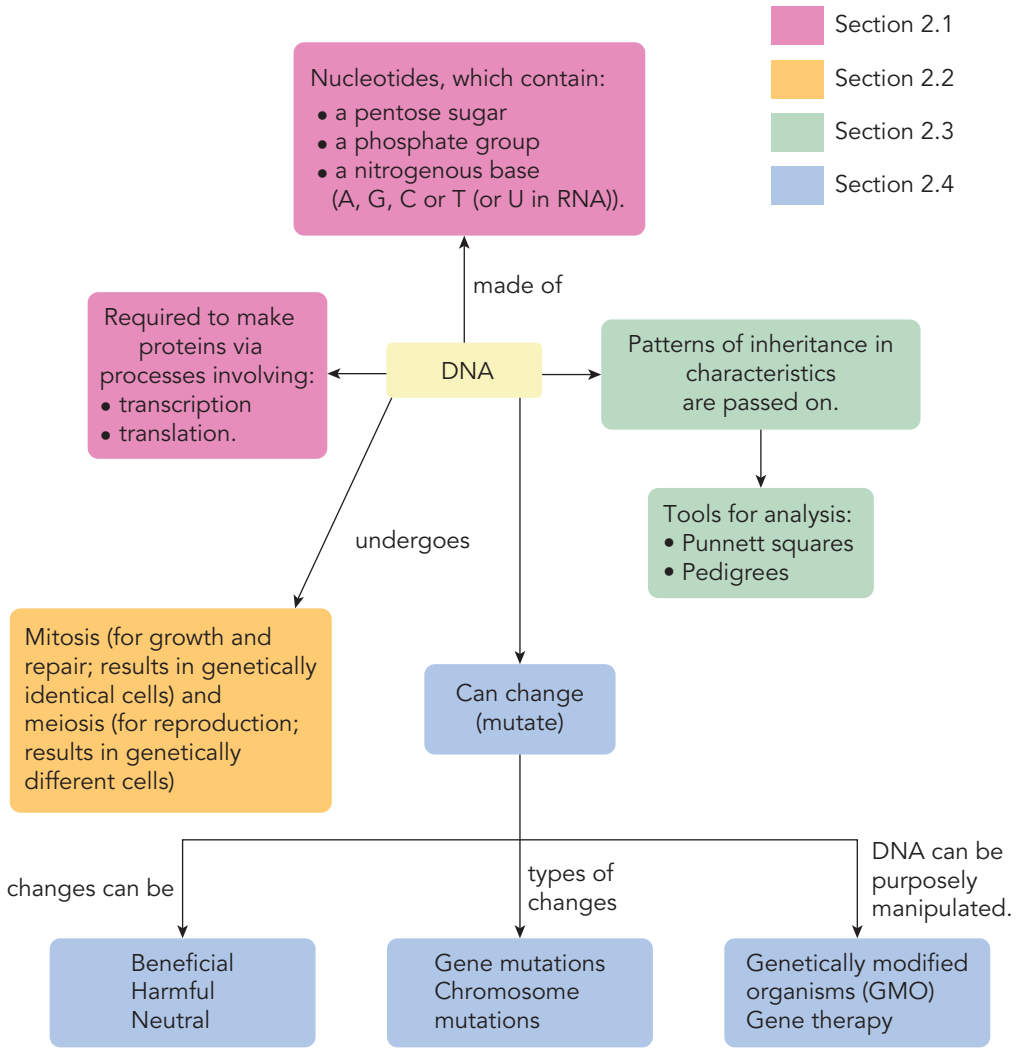
Chapter map



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Curriculum content

Biological sciences	
Cell division processes of meiosis and mitosis produce new cells with chromosome numbers specific to their role; chromosomes contain genes that are composed of DNA (deoxyribonucleic acid)	
• comparing the role and number of chromosomes in the cells produced by mitosis and meiosis	2.2
• modelling the structure of DNA	2.1
Patterns of monohybrid inheritance, including autosomal dominant/recessive and sex-linked recessive inheritance, can be predicted using pedigrees and Punnett square crosses	
• interpreting pedigrees and predicting offspring for autosomal dominant/recessive alleles, such as hair colour in guinea pigs, leaf colour in barley, seed shape and colour and plant height in peas	2.3
• interpreting pedigrees and predicting offspring for sex-linked recessive alleles, such as red-green colour blindness and haemophilia	2.3
Collaborating and applying	
Illustrate how advances in scientific understanding often rely on developments in technologies and engineering and technological and engineering advances are often linked to scientific discoveries	
• exploring how the development of fast computers has made the analysis of DNA sequencing possible	2.4
• examining how the work of Rosalind Franklin, James Watson, Francis Crick and Maurice Wilkins contributed to the development of the double helix structure of DNA	2.1
Illustrate how proposed scientific responses to contemporary issues may impact on society	
• examining karyotypes and applications of biotechnologies, such as DNA profiling, gene therapy and genetic engineering	2.2, 2.4
• investigating why agricultural practices have changed to include widespread use of genetically engineered crops	2.4

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Glossary terms

allele
aneuploidy
autosome
base triplet (codon)
carrier
centromere
chromatin
chromosome
chromosome mutation
codominance
complementary base pairing
crossing over
deletion
diploid (2*n*)
DNA
dominant
embryo
fertilisation
filial
gametes
gene
gene mutation
gene therapy
genetic engineering
genetic screening
genetically modified organism
genetics
genome
genotype
germline mutation
gonads
haploid (*n*)
heredity
heterozygous
homologous chromosomes
homozygous
hydrogen bonds
incomplete dominance
induced mutation
insertion
inversion
karyotype
locus
meiosis
mitosis
monogenic
monohybrid cross
monomer
mutagenic
mutation
non-disjunction
non-homologous chromosomes
nucleotide
ova
pedigree
phenotype
point mutation
polymer
polypeptide
Punnett square
recessive
recombination
reduction division
sex chromosomes
sexual reproduction
sister chromatids
somatic cells
somatic mutation
spontaneous mutation
stem cell
substitution
telomeres
test cross
transcription
transgenic organism
translation
trisomy
zygote

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2.1 Introduction to genetics and DNA

WORKSHEET
DNA structure

VIDEO
Structure of DNA

Learning goals

At the end of this section, I will be able to:

1. Recall the components that make up the structure of DNA and RNA molecules.
2. Describe the relationship between DNA, genes and chromosomes.
3. Describe the steps in which DNA is used to synthesise proteins.

Genetics

Genetics is the study of how certain traits (characteristics) can be inherited from a previous generation. It involves the study of **genes**, genetic variation and **heredity**. Genes are considered the basic unit of inheritance. They are made of **d**eoxyribo**n**ucleic **a**cid, or **DNA** for short. This hereditary material is passed from parents to offspring and contains the information needed to specify traits.

genetics
the study of genes, genetic variation and heredity

gene
a length of chromosome made of DNA; the basic unit of inheritance

heredity
the passing on of traits genetically from one generation to the next

DNA
deoxyribonucleic acid; the molecular unit of heredity, containing the genetic information responsible for the development and function of an organism

polymer
a molecule made from many repeating subunits called monomers

monomer
a single subunit that when joined together repeatedly makes a polymer

nucleotide
a monomer subunit of a nucleic acid, consisting of a phosphate group bound to a five-carbon sugar, which in turn is bound to a nitrogenous base

hydrogen bonds
chemical bonds that hold the two DNA strands together

Structure of DNA

DNA is a double-stranded molecule that forms a 'double helix' shape, like a twisted ladder. DNA is a **polymer** as it is made up of many **monomer** subunits called **nucleotides**.

The nucleotides that make up DNA have three major components:

- a five-carbon (pentose) deoxyribose sugar
- a nitrogenous base – one of adenine (A), guanine (G), cytosine (C) or thymine (T)
- a negatively charged phosphate group.

The nucleotides bind together to form two long strands that wind around each other. Each strand has a backbone made of alternating deoxyribose sugar and phosphate groups.

The nitrogenous bases from one strand bind to complementary bases on the other strand using **hydrogen bonds**.

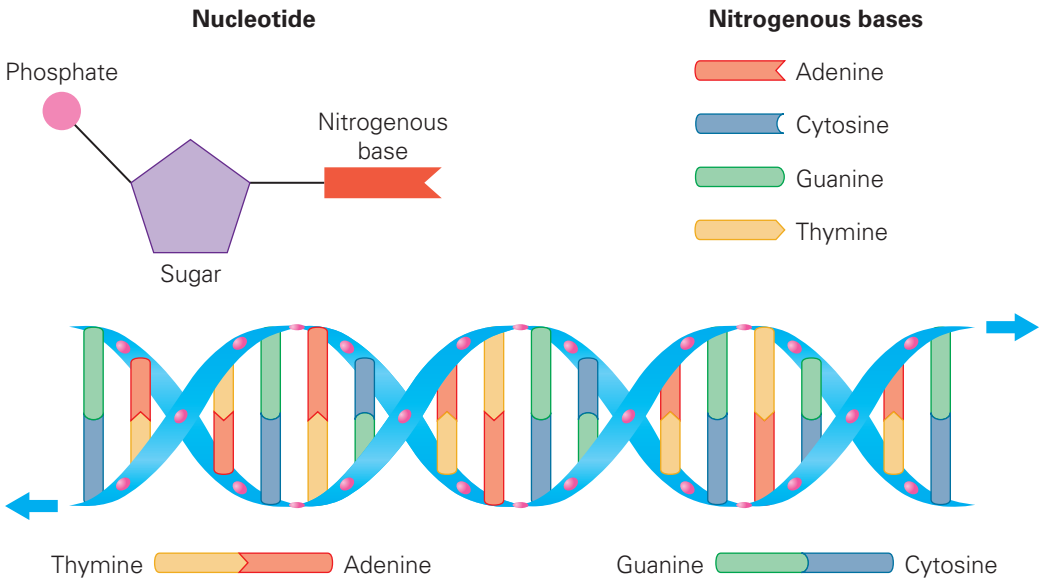

Figure 2.1 The double helix structure of DNA: the subunits called nucleotides all join up to form the double-stranded DNA. Note the sugar–phosphate backbone on the edge of the DNA molecule and the nitrogenous bases joining in the centre.

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Figure 2.2 Traits are passed on from generation to generation.

Adenine (A) always pairs with thymine (T), and guanine (G) always pairs with cytosine (C). One way to remember the A–T and G–C pairings is 'Apple in the Tree, Car in the Garage'. This **complementary base pairing** occurs because of the shape of the nitrogenous bases and the number of hydrogen bonds they can form (see Figure 2.3).

Guanine and adenine have a double-ring structure, which means they belong to a group of chemical molecules called purines. A helpful way to remember that adenine and guanine are purines is 'Pure As Gold'. Cytosine and thymine have a single-ring structure and belong to the group called pyrimidines. Purines always pair with pyrimidines, but the number of hydrogen bonds between them depends on the structure. Guanine binds with cytosine with three hydrogen bonds, while adenine and thymine form two hydrogen bonds.

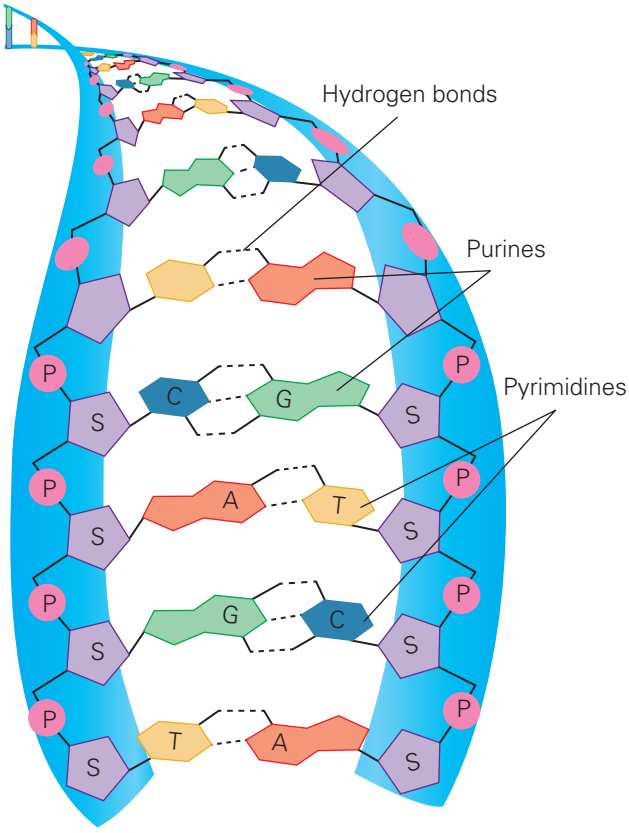

Figure 2.3 A closer look at the structure of DNA. The sugar–phosphate backbone forms the outer edge of the helix, and the nitrogenous bases form complementary pairs in the centre. Hydrogen bonds hold the two strands together.

complementary base pairing adenine only binds with thymine and cytosine only binds with guanine

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Try this 2.1

Modelling DNA using lollies

Be careful
Do not to consume lollies in the laboratory. Beware of allergies.

Materials

- liquorice ribbons or sour strips
- a handful of jelly babies
- toothpicks

Method

1. Sort the jelly babies into four groups of colours.
2. Pair up the jelly babies so that one particular colour always goes with another particular colour, for example, red with yellow and orange with green.
3. Place a pair of jelly babies onto each toothpick as if you were making lolly kebabs. Ensure that the pairs are always of matched colours.
4. Attach your lolly kebabs to the long strips of liquorice.
5. Keep doing this until you have about five to seven horizontal toothpicks attached and it starts to look a bit like a ladder.
6. The paired coloured sweets represent the base pairs, while the liquorice is the sugar–phosphate backbone.
7. Pick up your lolly ladder and twist it to represent the double helix shape of DNA.

Practical 2.1

Extracting DNA from cells

Be careful
Wear safety glasses and a lab coat. Do not consume food items.

Time period
Approximately one hour

Aim
To investigate and extract DNA from strawberries.

Materials

- plastic sandwich bag (or other material to contain strawberry and liquid)
- strawberry
- 10 mL DNA extraction solution provided
- filter funnel and gauze (or other gauze-style filter)
- cold ethanol solution
- test tube (or small beaker)
- stirring rod
- plastic pipette

DNA extraction solution

- 5 mL dishwashing liquid or shampoo
- 0.75 g table salt
- 45 mL water

continued …

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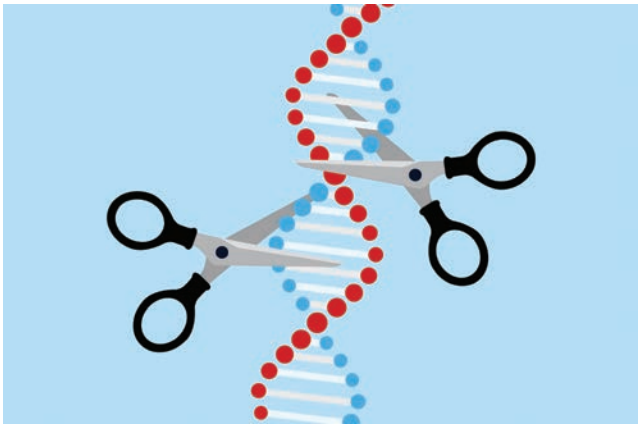
Method

1. Wash the strawberry with tap water and remove the green leaves. Add the strawberry to the plastic sandwich bag.
2. Add the DNA extraction solution (10 mL) and close the sandwich bag, removing the excess air.
3. Squash the strawberry into the liquid using your hands until the strawberry is roughly crushed.
4. Pour the strawberry mixture through a filter funnel lined with gauze into a test tube.
5. Discard the gauze and strawberry remains into a bin.
6. Add an equal volume of cold ethanol to the test tube using a plastic pipette.



7. Slowly mix the two layers of liquid with a stirring rod.
8. Collect the white solid that forms on the stirring rod. This is DNA.

Results

Write observations for what occurs during each step of the method.

Discussion

1. Describe whether the white solid could contain all of the DNA of the strawberry.
2. Visually compare the amount of solid you collected to that of other groups in the classroom. Were results consistent? Explain your answer.
3. Describe the variables that were not kept consistent between groups in the classroom.
4. Suggest any changes that could be made to the method to improve the quality of the recorded data in future experiments. Justify your suggestions by explaining how each change would improve the data quality.

Conclusion

1. Draw a conclusion regarding the efficiency of this method at extracting all the DNA from a strawberry, based on your and other groups' observations.

Did you know? 2.1

How long is DNA?

The DNA found in only one cell, if fully unravelled, would be around two or more metres long! The length of a piece of double-stranded DNA is commonly expressed as the number of complementary nitrogenous base pairs it contains. The DNA in an average human cell has an estimated 63 000 000 base pairs.

Quick check 2.1

1. **Recall** the three key components that make up a nucleotide.
2. **Describe** the overall shape of DNA.
3. If a strand of DNA contained the nitrogenous bases seen below, **state** the bases in its complementary strand. DNA strand: ATATAGATAGATCAGACA.

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Explore! 2.1

The discovery of DNA

Friedrich Miescher was a Swiss biochemist who first observed DNA in 1869. However, it took almost a century for scientists to understand the structure of DNA and the mechanisms by which it carries genetic information.

Research the following scientists who, among many others, contributed to our understanding of DNA:

- Friedrich Miescher
- Erwin Chargaff
- Francis Crick and James Watson
- Rosalind Franklin and Raymond Gosling
- Maurice Wilkins.

Summarise their contributions and place them on a timeline.

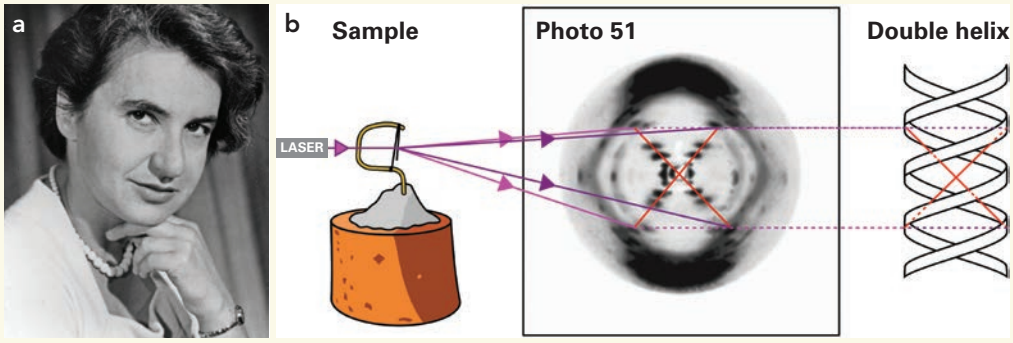

Figure 2.4 Dr Rosalind Franklin **(a)** and Raymond Gosling fired X-rays at a DNA strand stretched across a paperclip **(b)** in 1952.

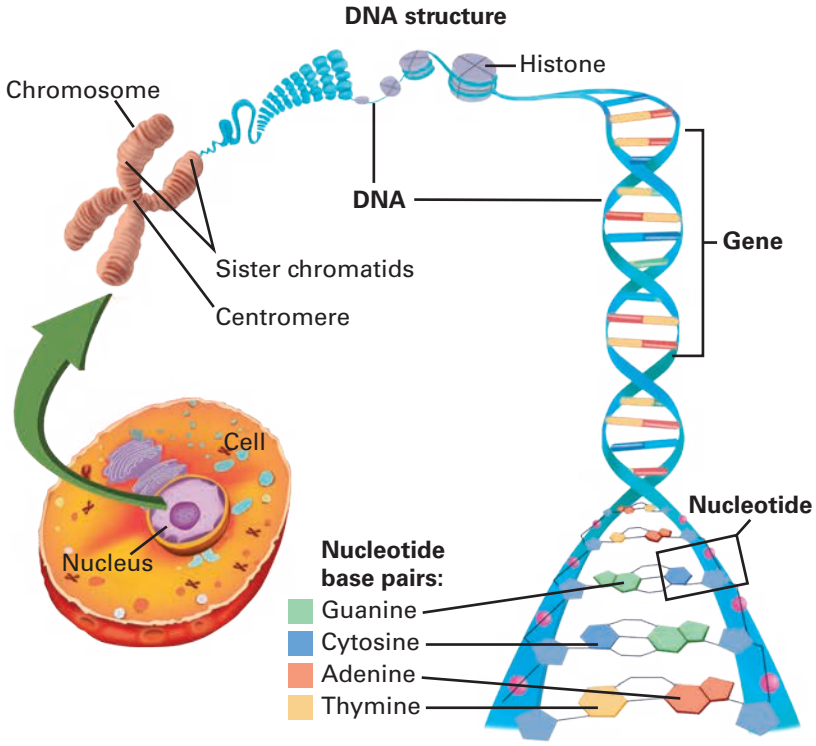

Figure 2.5 The relationship between DNA and chromosomes

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What is a chromosome?

The DNA found in the nucleus of a cell is usually in a form called **chromatin**. This is a highly organised complex of DNA and associated proteins such as histones. By wrapping around histones, the long strands of DNA can fit inside the nucleus. When it is time for the cell to replicate, chromatin condenses into structures called **chromosomes**. Each molecule of DNA forms one chromosome. Along the chromosome are genes, which are the units of inheritance. Genes are sections of DNA that hold the specific instructions required for making every protein in our bodies.

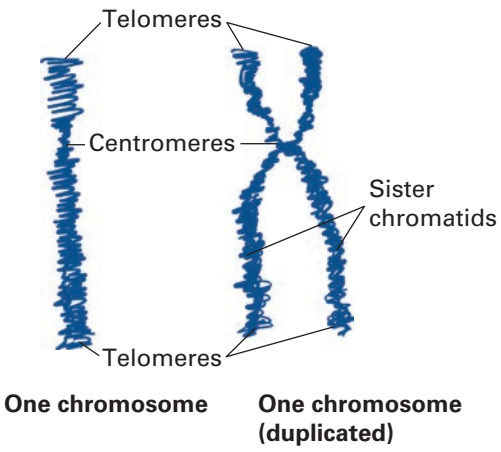

Figure 2.6 Before replication, a chromosome is a single molecule (left). After DNA replication, each chromosome consists of two molecules called sister chromatids (right).

The familiar X-shape of a chromosome is only seen after DNA replication has occurred. Shortly before replication, the chromosome appears as a single condensed DNA molecule. DNA replication produces two identical **sister chromatids** that are joined together by **centromeres** to form the distinct X-shape (see Figure 2.6). At the ends of each chromosome are protective structures made of DNA and protein called **telomeres**. These protect the chromosomes, but every time DNA replicates, the telomeres shorten. Eventually, the telomeres shorten to the extent that replication can no longer occur.

VIDEO
DNA and RNA

chromatin
a mixture of DNA and proteins that forms chromosomes

chromosome
a thread-like structure of tightly wound DNA and proteins

sister chromatids
two copies of the same chromosome, connected at a centromere

centromere
a structure that holds two sister chromatids together

telomeres
structures made from DNA and proteins that protect the ends of chromosomes

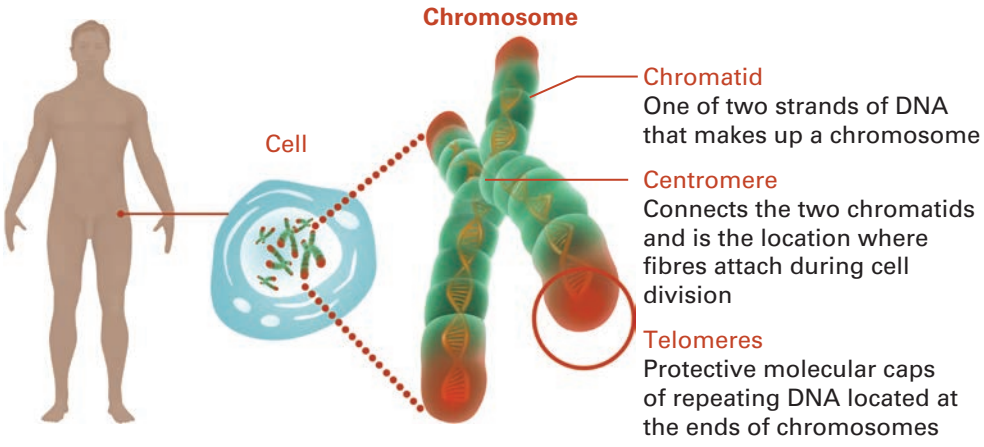
Chromosome
Cell
Chromatid
One of two strands of DNA that makes up a chromosome
Centromere
Connects the two chromatids and is the location where fibres attach during cell division
Telomeres
Protective molecular caps of repeating DNA located at the ends of chromosomes

Figure 2.7 The distinct X-shaped chromosome, showing the two sister chromatids and the centromere

Figure 2.8 A scanning electron micrograph of a duplicated human chromosome

Making thinking visible 2.1

Compass points: Telomeres and immortality

Telomeres contain thousands of repeated copies of the base sequence TTAGGG. When we are infants, our telomeres are approximately 10 000 bases long, but each time the cell divides, they slowly get shorter. A cell will die when its telomeres become too short. By the time we are in our eighties, our telomeres may only be 5000 bases long, but this varies from tissue to tissue and from person to person. A person in their thirties may well have telomere lengths of a person in their nineties and vice versa.

continued ...

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This means that telomeres are a key component of ageing, and there are efforts to use them to slow down or reverse the ageing process. Some companies say they can measure your telomere length, suggesting that it will indicate your true, biological age. Despite limited evidence, there are also companies that sell products that they claim can maintain or lengthen telomeres – in effect, making you younger or possibly allowing immortality.

Complete the Compass points activity about manipulating telomeres to prevent ageing:

1. E = Enthusiastic: What generates enthusiasm within you regarding this concept? What are the potential benefits?
2. W = Worries: What causes concern about this idea? What are the potential drawbacks?
3. N = Need for information: What other details or facts are necessary to evaluate this idea? What additional knowledge would aid in assessment?
4. S = Suggestion for progress: What is your current viewpoint or proposal regarding this idea? How can you continue to assess this concept?

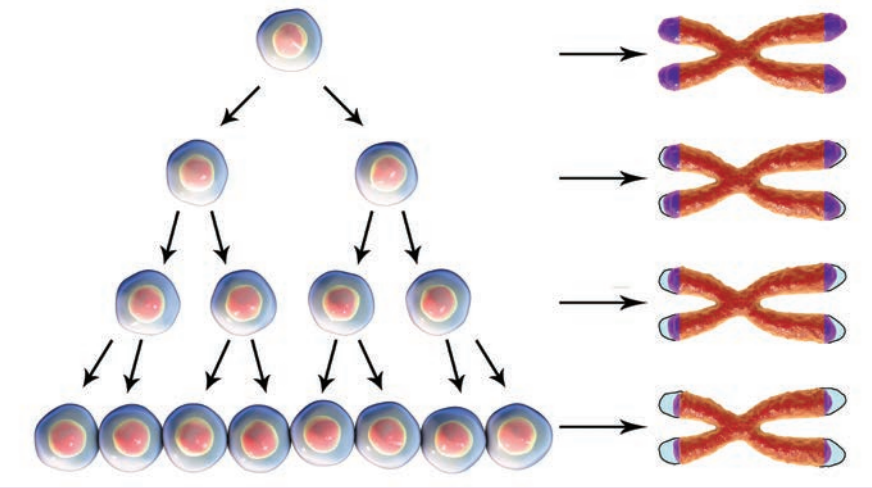

Figure 2.9 Telomeres shorten every time a cell divides.

The *Compass points* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

	DNA	RNA
Number of strands	Two	One
Type of sugar	Deoxyribose	Ribose
Nitrogenous bases	Guanine Cytosine Adenine Thymine	Guanine Cytosine Adenine Uracil
Where is the molecule found?	Nucleus, mitochondria and chloroplasts (in eukaryotes) Cytoplasm (in prokaryotes)	Cytoplasm Nucleus Associated with ribosomes
Different forms	DNA Mitochondrial DNA (mtDNA) Chloroplast DNA (cpDNA)	Messenger RNA (mRNA) Transfer RNA (tRNA) Ribosomal RNA (rRNA)

Table 2.1 The main differences between the two nucleic acids, DNA and RNA

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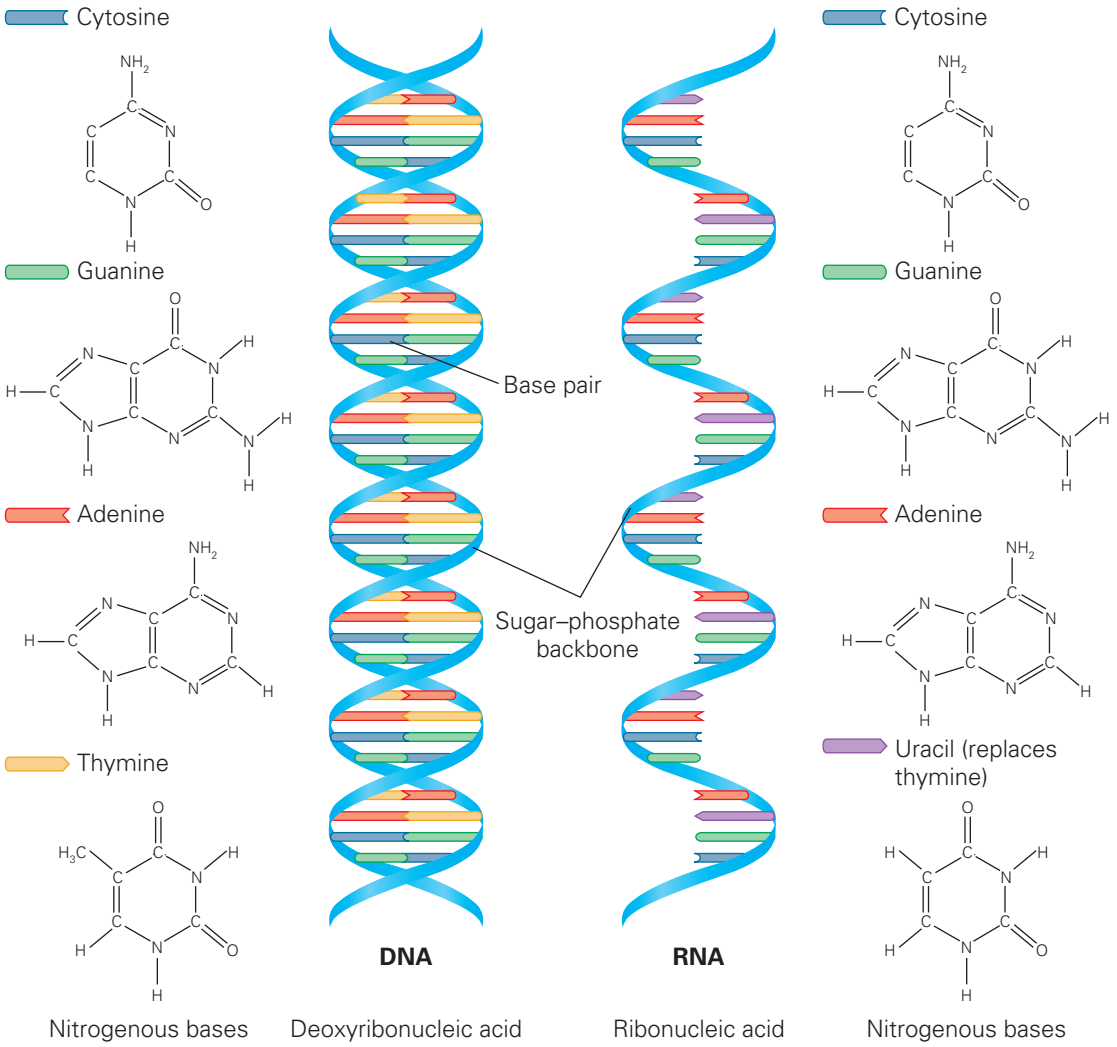

Figure 2.10 DNA and RNA

Different forms of nucleic acids

There are four types of biological macromolecules: proteins, carbohydrates, lipids (fats and oils) and nucleic acids. Nucleic acids are found in two forms: DNA and ribonucleic acid (RNA). The two types of nucleic acids differ in several key ways, which are outlined in Table 2.1 and shown in Figure 2.10.

Quick check 2.2

1. **Describe** the relationship between chromosomes, genes, DNA and base pairs.
2. **Contrast** the structures of DNA and RNA.

The purpose of DNA: Making proteins

Why do we need proteins?

Proteins are complex molecules that play a critical role in many body functions. We use approximately one billion proteins every day, just to function normally. Proteins help provide structure to cells and build and repair tissue. Protein molecules play many other varied roles in the body; they include haemoglobin molecules that carry oxygen around our body and the hormones that regulate our glucose levels and development. Collagen and keratin are structural proteins, making up the structural components of organs. Enzymes such as amylase and lipase are catalytic proteins that help control the rates of reactions. Other proteins help us fight pathogens, transport molecules and move our muscles.

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Explore! 2.2

Protein functions

The many roles of protein include structural, contractile, transport, catalytic, regulatory and immunological functions. Research the following proteins and determine their function.

Protein	Function
Oxytocin	
Actin	
Ferritin	
Insulin	

The link between DNA and proteins

Genes are sections of DNA that hold the specific instructions required for making each of the proteins in our bodies. The sequence of the nitrogenous bases in a gene provides the instructions (or code) to produce a protein. A group of three nitrogenous bases is called a **base triplet** or **codon**, and these code for a particular amino acid. Amino acids are the monomers of proteins. The order of nitrogenous bases specifies the sequence of amino acids that forms a particular protein.

base triplet (codon) a set of three nitrogenous bases that code for an amino acid

transcription the first stage of protein synthesis in which the base sequence of DNA is copied into mRNA

translation the second stage of protein synthesis in which a sequence of mRNA is translated into a sequence of amino acids

Quick check 2.3

1. **Recall** why proteins are important.
2. **Describe** the relationship between DNA, amino acids and proteins.

Protein synthesis

To synthesise (or build) proteins using the DNA code in genes, the gene must be expressed; that is, the instruction in the DNA is converted into a protein. This means two processes need to occur: **transcription** and **translation**.

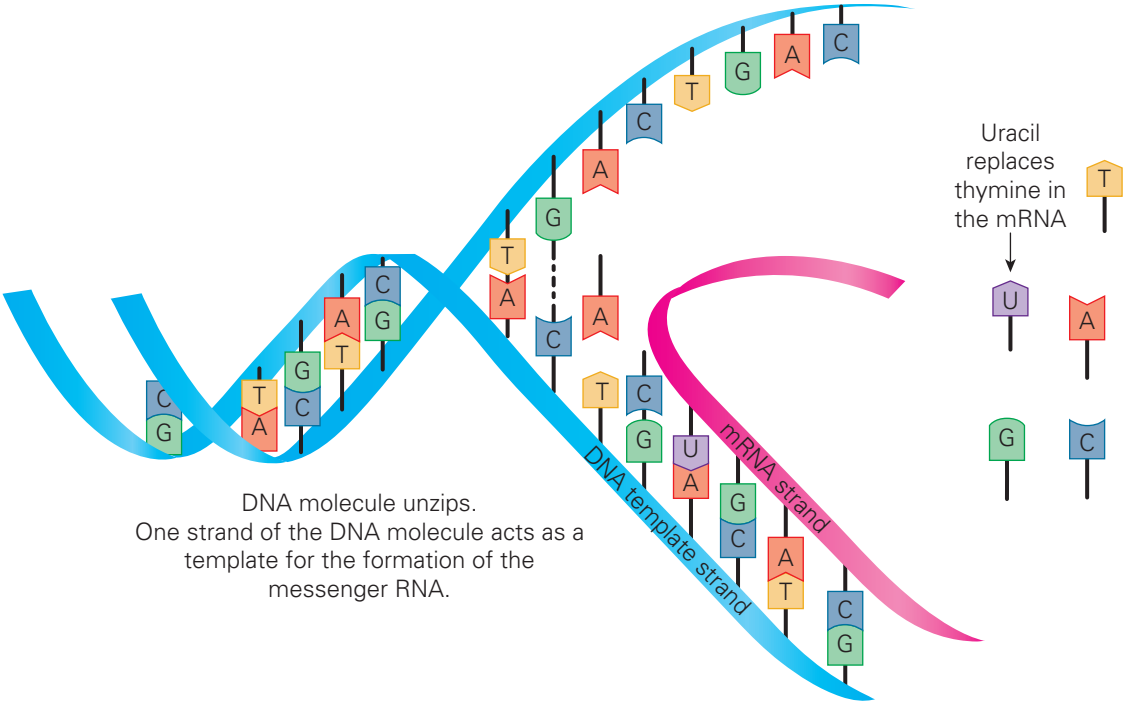
Uracil replaces thymine in the mRNA
DNA molecule unzips. One strand of the DNA molecule acts as a template for the formation of the messenger RNA.
mRNA strand
DNA template strand

Figure 2.11 When the DNA double helix unwinds and unzips, one strand of the DNA acts as the template on which the messenger RNA strand is formed.

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To transcribe means to put into written form, so in this process the DNA code for a specific protein is 'written down' in the form of mRNA (messenger RNA).

To translate means to convert into another form, so in this process the code (written down as mRNA) is converted into a chain of amino acids known as a polypeptide chain. This can then be folded to become a protein.

Transcription

Transcription happens in the nucleus of the cell. The transcription process requires getting access to the DNA code in the genes, otherwise the code cannot be copied. Transcription begins when an enzyme (RNA polymerase) binds to the gene being copied. This causes the DNA double helix to unwind, allowing the enzyme to read the code on one of the DNA strands (called the DNA template strand). As the enzyme reads the code, it builds a complementary copy of the gene using RNA nucleotides: C, G, A and U. RNA follows the same complementary pairing rules as DNA, with one exception. Where DNA has the nitrogenous base thymine (T), RNA has uracil (U). The newly formed single-stranded RNA is called messenger RNA (mRNA). When transcribing DNA into mRNA, only one strand of DNA is used as a template. If both strands were transcribed, it would result in two different RNA sequences coding for different proteins, leading to confusion and potentially incorrect protein synthesis. When the mRNA peels away from the DNA template strand, the DNA double strands rejoin and wind back up into a helix. The mRNA then leaves the nucleus and goes to the sites of protein production, the ribosomes.

Try this 2.2

Base pairings

Complete the base sequence of the complementary DNA strand and then the mRNA strand formed from the DNA template strand given below.

Complementary DNA	
DNA template	T A C C C G A A A G T G
mRNA	

Translation

Once mRNA reaches the ribosomes in the cytoplasm, it must be 'decoded' or translated to make the necessary protein. The nitrogenous bases in the mRNA are decoded in codons. Each codon in the mRNA specifies which amino acid is added to the **polypeptide** chain.

WIDGET
Building a protein

polypeptide
a chain of amino acids, forming part or the whole of a protein molecule

Figure 2.12 simplifies the process of translation. In reality, translation requires several enzymes and another type of RNA called transfer RNA (tRNA). It occurs at the ribosomes, which may be freely floating in the cytoplasm or attached to the endoplasmic reticulum (ER), creating the rough ER. Each tRNA molecule transports one specific amino acid towards the ribosome for delivery.

Table 2.2 shows the 20 different amino acids that form the building blocks for every protein. Using this table, you can identify the amino acid that each codon codes for. For example, if the first codon of your mRNA strand is AUG, you locate the A in the left column and the U in the top row and find where they intersect. At that spot is a box containing four different codons. You then find where the G in the right column of the table intersects and you will see your codon AUG. Next to the codon it says Met, which means AUG codes for the amino acid methionine

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in eukaryotes. The codon AUG is unique as it is also a START codon. This means that it always is the first codon in the transcribed mRNA that undergoes translation. There are also three STOP codons, which signal for the process of translation to stop rather than coding for another amino acid.

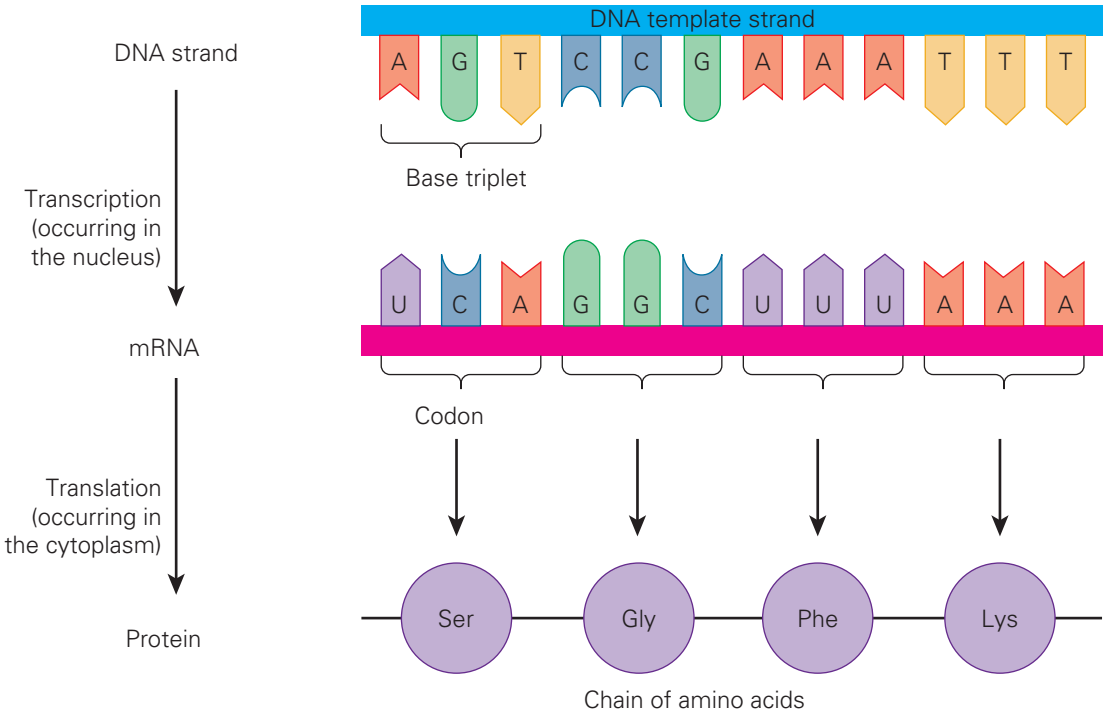

Figure 2.12 The process of transcription and translation from a DNA molecule to an amino acid chain

Second letter in the codon

First letter in the codon	U		C		A		G		Third letter in the codon
U	UUU	Phe (F)	UCU	Ser (S)	UAU	Tyr (Y)	UGU	Cys (C)	U
	UUC		UCC		UAC		UGC		C
	UUA	Leu (L)	UCA		UAA	STOP	UGA	STOP	A
	UUG		UCG		UAG	STOP	UGG	Trp (W)	G
C	CUU	Leu (L)	CCU	Pro (P)	CAU	His (H)	CGU	Arg (R)	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Gln (Q)	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	Ile (I)	ACU	Thr (T)	AAU	Asn (N)	AGU	Ser (S)	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lys (K)	AGA	Arg (R)	A
	AUG	Met (M) START	ACG		AAG		AGG		G
G	GUU	Val (V)	GCU	Ala (A)	GAU	Asp (D)	GGU	Gly (G)	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	Glu (E)	GGA		A
	GUG		GCG		GAG		GGG		G

Table 2.2 Table of amino acids showing that the genetic code is degenerate, which means that more than one codon can code for a single amino acid. This redundancy means that 61 of the 64 codons code for the 20 amino acids (the other three are stop codons).

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Did you know? 2.2

Using biotechnology to produce therapeutic proteins

Traditionally, vaccines contain a weakened virus, or a protein of the virus, to trigger the body's immune response and provide immunity.

Two of the common COVID-19 vaccines work in that way. AstraZeneca (a viral vector vaccine) contains material from the SARS-CoV-2 virus within the shell of another virus. Novavax (a protein subunit vaccine) contains part of the coronavirus spike protein, which is injected directly.

mRNA vaccines have been in development for decades but had been progressing slowly. Financial backing from governments and commercial organisations is critical for research, and the significant funding provided worldwide to address the COVID-19 pandemic accelerated mRNA vaccine biotechnology.

mRNA vaccines work differently to traditional vaccines. Instead of delivering a viral protein, the vaccines deliver mRNA. COVID-19 mRNA vaccines contain instructions for making the spike protein from the SARS-CoV-2 virus. The Pfizer and Moderna vaccines package the mRNA into a lipid nanoparticle that can pass through the cell membrane.

Vaccine mRNA is modified to be more efficient at protein synthesis and resistant to degradation. This means it can be used as a template many times. Manufacturers use computer-controlled techniques for generating the required strands of RNA. This method is cheaper and safer than manufacturing proteins or growing viruses. mRNA vaccines have huge potential for preventing and controlling future epidemics and pandemics.

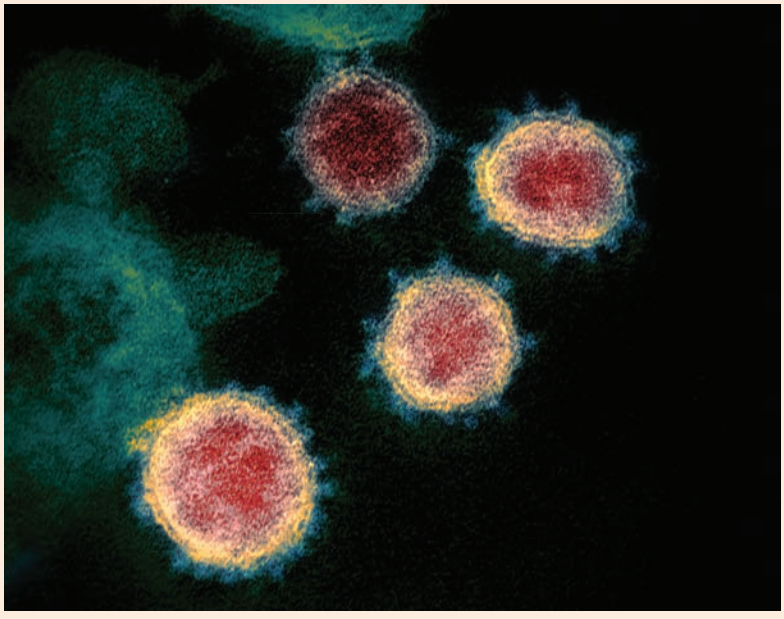

Figure 2.13 A colourised electron microscope image of SARS-CoV-2 virus particles. The spike proteins around the edge give coronaviruses their name, as *corona* is Latin for crown.

Quick check 2.4

1. The following codons are found in a strand of DNA: TAA TTA TCG ACT ACT AGC.
   State the complementary mRNA strand.
2. **Contrast** transcription and translation.
3. **Explain** why you do not need to read the code on both strands of DNA when transcribing DNA into mRNA.

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Go online to access the interactive section review and more!

Section 2.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.1 questions

Remembering

1. **Name** the basic building blocks or monomers of DNA.
2. **Recall** where proteins are created (synthesised) in the cell.
3. **Recall** the name for the shape of DNA.
4. **Illustrate** and label a nucleotide.
5. **Recall** the four bases found in DNA and the complementary base pair rule.
6. **Recall** why all mRNA strands start with the codon AUG.

Understanding

7. A template strand of DNA is found to contain the following bases: TAC GGA TCA TCG TGG GAA GCA GGC ATT.
   a) **State** the complementary DNA strand.
   b) Using the above template strand of DNA, **state** the bases on the mRNA strand.
   c) Using Table 2.2, **identify** the amino acids that this strand of DNA would code for.

Applying

8. **Describe** the purpose of DNA.
9. **Describe** the relationship between DNA, genes and chromosomes.
10. **Explain** how a cell produces so many different proteins with only four different nitrogenous bases.
11. **Explain** how the genetic information found in the chromosomes within the nucleus of a cell reaches the ribosomes for protein synthesis.
12. Make a flow chart to **summarise** the key steps in transcription and translation.

Analysing

13. **Contrast** the structures of mRNA and DNA.
14. **Differentiate** between the functions of a structural protein and a catalytic protein, providing examples of each.

Evaluating

15. A template strand of DNA is found to contain the following bases: TCC TGA TGA TGG GGG GCA AAA CGC GTA.
    Something went wrong during the transcription of this template strand, and the mRNA strand contains the following bases:
    AGG ACU ACU ACC CUC CGU UUU GCG CAU.
    a) **Determine** the mistake in the mRNA strand above.
    b) **Propose** the outcome of this mistake on the protein produced.
16. **Propose** what may occur if there was a problem with a certain protein in your body.

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2.2 Passing on genetic information

Learning goals

At the end of this section, I will be able to:

1. Recall the steps involved in DNA replication.
2. Describe the stages of cell division in mitosis and meiosis.
3. Use a karyotype to determine information about an individual.

WORKSHEET DNA replication and reproduction

VIDEO Sexual reproduction

Two different forms of reproduction occur among organisms: asexual and **sexual reproduction.** Sexual reproduction requires two organisms to each contribute a **gamete**; these are the sex cells that combine to produce a unique offspring. Gametes are formed in the **gonads** of the male (testes) and the female (ovaries). Each gamete contains half the genetic information needed to form a new organism of the same species. When the gametes – sperm and **ova** (eggs) – meet and fertilise, they form a **zygote** with a full set of genetic information. The zygote divides and as the number of cells increases, cells begin to take on special functions. Eventually, the zygote becomes an **embryo**.

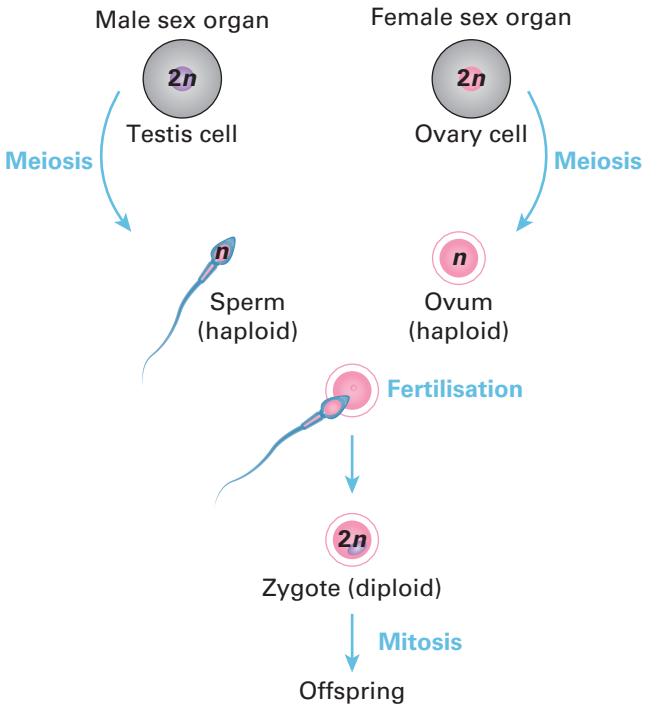

Figure 2.14 Sexual reproduction involves a gamete from a male and a gamete from a female combining to form a zygote.

You will notice that Figure 2.14 has some new terms:

- Cells that contain only one set of chromosomes are known as **haploid (*n*)**. Gametes are haploid.
- Cells that contain two sets of chromosomes are known as **diploid (2*n*)**. **Somatic cells** (body cells) and the zygote are all diploid.
- **Meiosis** is the name of the process by which the gonads make the haploid gametes.
- **Mitosis** is the name of the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair.

In humans, the haploid number (n) is 23. This means that gametes contain 23 single unpaired chromosomes. When the egg and sperm meet and fertilise, the two sets of chromosomes come together and form the diploid zygote ($2n$). The zygote contains 23 pairs of chromosomes, meaning the diploid number ($2n$) in humans is 46. The haploid and diploid numbers vary between species, but always remain the same for all the organisms within that species. For example, a platypus has a diploid number ($2n$) of 52, which means it has 26 pairs of chromosomes in its somatic cells. This also means the egg and sperm of a platypus contain half this amount of genetic information, so its haploid number (n) is 26 chromosomes.

sexual reproduction a form of reproduction that involves the fusion of gametes from two parents and introduces variation to the offspring

gametes sex cells (sperm and ova) with half the usual number of chromosomes

gonads the sexual organs: testes in males and ovaries in females

ova (singular: ovum) mature female reproductive cells

zygote a fertilised egg produced by the fusion of male (sperm) and female (ovum) gametes

embryo the initial stage of early development in multicellular organisms

haploid (*n*) a cell containing only one set of unpaired chromosomes

diploid (2*n*) a cell containing two sets of chromosomes

somatic cells the body cells of an organism

meiosis the process by which the gonads make gametes, which are haploid

mitosis the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

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Did you know? 2.3

Different diploid numbers

The diploid number of chromosomes in a species is not related to whether an organism is bigger or more complicated. For example, a koala, a tammar wallaby and garlic all have a diploid number of 16 but are very different!

Figure 2.15 Some very different organisms contain the same diploid number of chromosomes.

Quick check 2.5

1. **Differentiate** between the terms 'haploid cell' and 'diploid cell', providing an example of each.
2. If a sheep's body (somatic) cell contained 54 chromosomes, **calculate** how many chromosomes would be found in its gametes.

How does DNA copy itself?

mutation
a change in the genetic code of a cell

Before a cell divides, the DNA must be replicated to provide two copies of each chromosome, one for each new cell. This occurs before the processes of mitosis and meiosis. DNA replication must be precise, otherwise errors can affect the code in the DNA and lead to **mutations** (permanent changes in the DNA). The steps involved in DNA replication are outlined below and summarised in Figure 2.16.

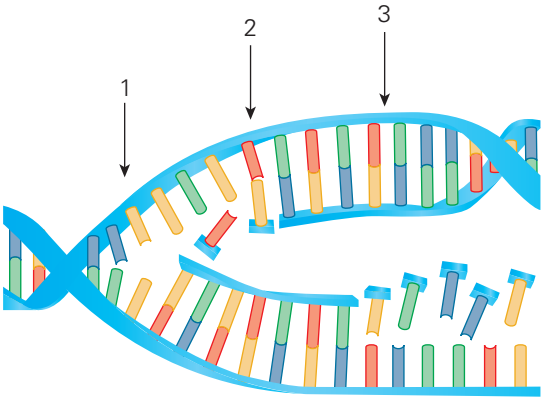

Figure 2.16 DNA replication: (1) the DNA must first unwind and unzip and then (2) the new DNA nucleotides can be added following complementary base pairing rules. (3) This results in two identical strands of DNA.

1. The DNA molecule unwinds and 'unzips' (breaks the hydrogen bonds) between the nitrogenous bases. This happens with the help of an enzyme called DNA helicase.
2. Another enzyme called DNA polymerase attaches new nucleotides to the exposed nitrogenous bases. The enzyme follows the complementary pairing rule, where adenine can only join with thymine, and cytosine can only join with guanine. The two new strands of DNA will be identical to the original parent strand.
3. The newly added nucleotides are connected with new hydrogen bonds, which results in two identical strands of double-stranded DNA being formed. Each new strand is one-half of the original strand and one-half that was newly built. For this reason, replication is sometimes described as being semi-conservative because half of the original DNA molecule is conserved in each of the two new molecules.

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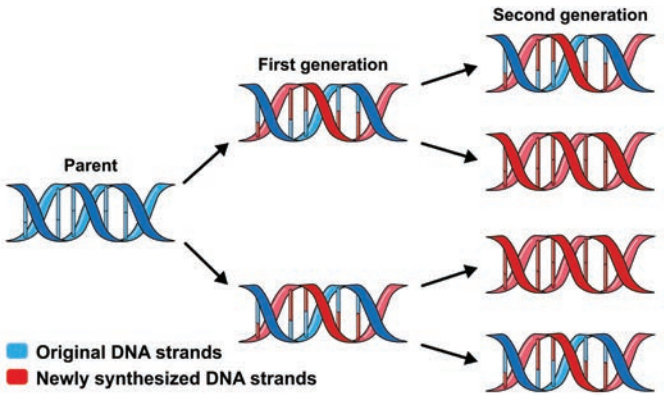


Figure 2.17 DNA replication is described as semi-conservative because the two new strands of DNA each contain one parent strand and one newly synthesised strand.

Quick check 2.6

1. **Explain** the purpose of DNA replication.
2. **Summarise** the steps of DNA replication.

Mitosis

Growth and repair of damaged tissues requires a form of cell division called mitosis. Mitosis is also important in asexual reproduction to make identical copies of cells. The diploid ($2n$) parent cell divides to form two diploid cells that are genetically identical, called daughter cells. The sequence of steps in mitosis is shown in Table 2.3. Mitosis produces every cell in the human body, except gametes, which are produced by meiosis and result in haploid (n) cells.

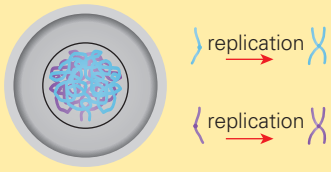
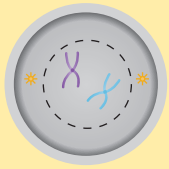
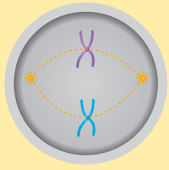
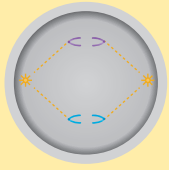
The stages of mitosis		
Interphase $2n$ (before mitosis)		• The parent cell is diploid ($2n$). • DNA replication occurs. • Chromosomes are not visible. • The cell gets bigger. • Organelles replicate.
Prophase		• The nuclear membrane breaks down. • DNA condenses and appears as distinct chromosomes. • Spindle fibres begin to form.
Metaphase		• Chromosomes are arranged along the centre of the cell. • Each chromosome is attached to a spindle fibre by the centromere.
Anaphase		• The sister chromatids split at the centromere and are pulled to either end of the cell by the spindle, centromere first. • Spindle fibres then begin to disappear.

Table 2.3 The stages of mitosis

continued …

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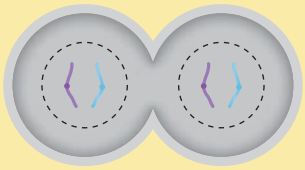
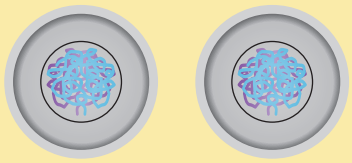
The stages of mitosis		
Telophase		• The nuclear membrane re-forms around the two sets of chromosomes, forming two new nuclei. • The chromosomes decondense and are no longer visible.
Cytokinesis 2 × 2*n* (after mitosis)		• The division of cytoplasm starts. • The cell pinches in half and divides into two genetically identical diploid daughter cells. • In plant cells, a structure called the cell plate forms and transforms into a new cell wall.

Table 2.3 *(continued)*

Quick check 2.7

1. **State** which cells undergo mitosis.
2. **Summarise** the steps of mitosis.

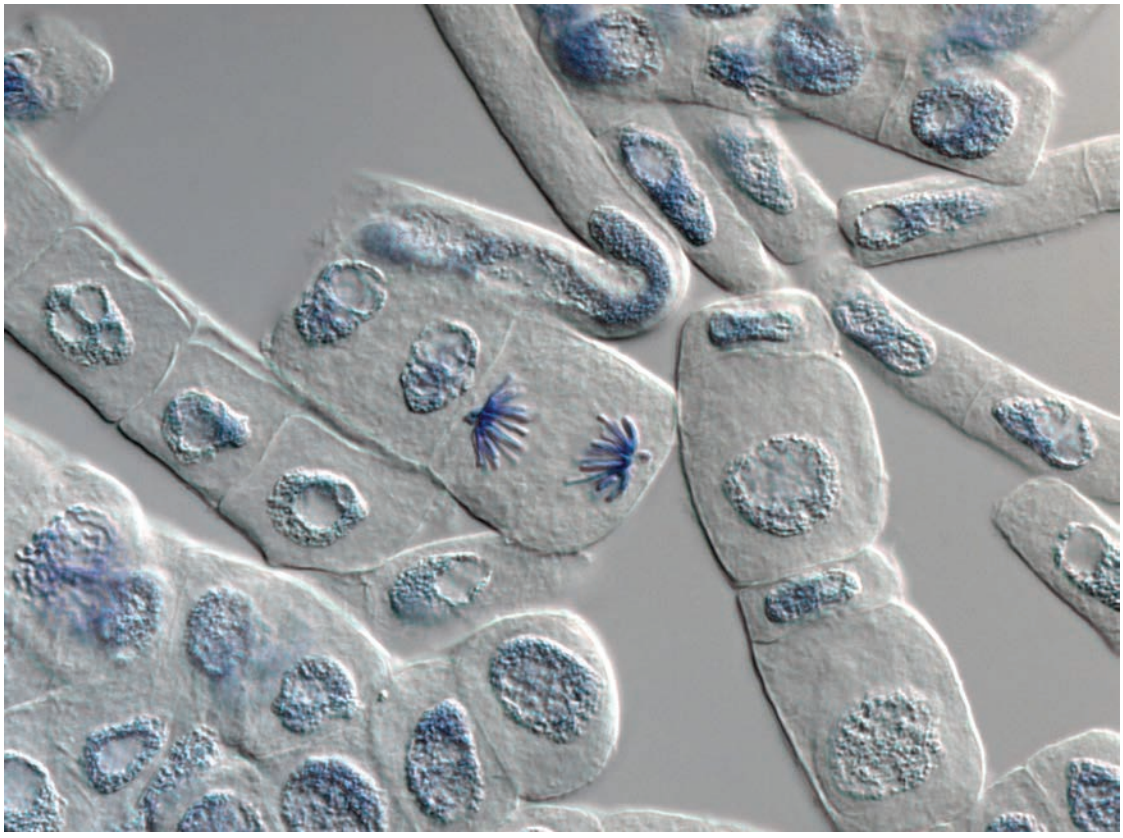


Figure 2.18 Plant cells in the process of mitosis viewed under a light microscope. The central cell shows the chromosomes moving to each end of the cell in anaphase. Can you identify some of the other stages?

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Practical 2.2

Observing cells in a dividing root tip

Be careful

Ensure you carry the microscope appropriately: hold the arm with one hand and place one hand under the base. Ensure you don't make big changes in magnification, so as not to damage the glass slide.

Aim

To observe cells carrying out mitosis in a growing onion root tip.

Materials

- prepared, stained slide of the growing section of an onion root tip caught at different stages of cell division
- microscope

Method

1. Using the lowest magnification, place a prepared slide of a growing onion root tip on the stage of the microscope.
2. Position the slide so that the pointed narrow end of the root tip is clearly visible.
3. Look for a cluster of rapidly growing cells near this region.
4. Observe several different cells at various stages of cell division under the highest magnification of the microscope.

Results

Carefully choose one cell with a clearly outlined cell wall and showing chromosomes in a certain stage of cell division. Sketch a copy of what you observed, labelling the cell wall and the chromosomes. Remember to use a sharp pencil and to document the magnification the sketch is taken at.

Data processing

1. The mitotic index is a quantitative expression of the amount of cell division that a particular tissue is undergoing. It is the ratio of the number of cells undergoing mitosis to the number of cells that are not undergoing mitosis. It can be calculated using the following equation:

$$\text{Mitotic index} = \frac{\text{number of cells in the field of view undergoing division}}{\text{total number of cells in the field of view}}$$

   Calculate the mitotic index for the tissue sample you have observed with your microscope.
2. Using the field of view in your microscope, complete the table and calculate the percentage of cells in each cell cycle stage.

Cell cycle stage	Number of cells in that stage	Percentage of cells in that stage
Interphase		
Prophase		
Metaphase		
Anaphase		
Telophase		
Total		

3. Use the calculated percentages to predict which cell cycle stage is the longest and which is the shortest in your sample of cells. Explain your answer.

Discussion

1. Explain how you could tell which cells were dividing.
2. Describe the main features of each stage of cell division. Could you use these to identify the stage of mitosis for a particular cell?
3. List the structures in the cells you could observe. Which structures were present that you could not observe? Why might this be the case?

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Meiosis

Meiosis is the process by which animals and plants produce gametes for sexual reproduction. It starts with a diploid ($2n$) parent cell, which contains two sets of chromosomes – one from each parent. To ensure that offspring receive the correct number of chromosomes, meiosis reduces the chromosome number by half, producing four haploid (n) daughter cells (gametes). This reduction in genetic material is why meiosis is called a **reduction division**.

reduction division cell division which results in a reduction of genetic material in the daughter cells

homologous chromosomes a matching pair of chromosomes, with one having been inherited from each parent; they have the same gene sequence and loci, length and centromere position

crossing over the exchange of genetic material between homologous chromosomes during meiosis, leading to genetic diversity in gametes

Meiosis occurs in two stages: meiosis I and meiosis II. Meiosis I separates homologous chromosome pairs, reducing the chromosome number from diploid to haploid. Meiosis II then divides the sister chromatids of each chromosome, similar to mitosis, ensuring that each gamete has a complete set of single chromosomes. These two divisions are essential for maintaining chromosome number across generations and increasing genetic diversity.

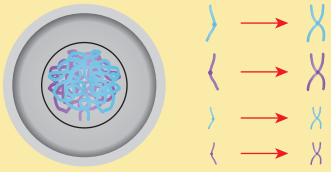
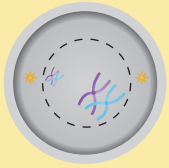
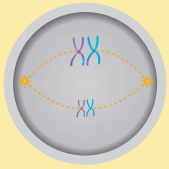
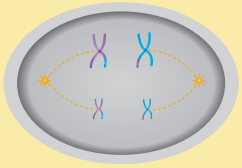
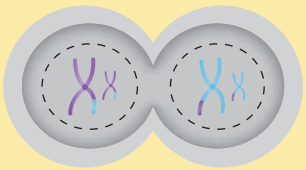
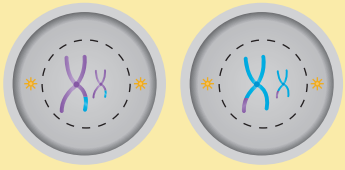
Meiosis I		
Interphase $2n$ (before meiosis)		• The parent cell is diploid ($2n$). • DNA replication occurs. • Chromosomes are not visible. • The cell gets bigger. • Organelles replicate.
Prophase I		• The nuclear membrane breaks down, the DNA condenses and chromosomes become visible. • **Homologous chromosomes** pair up and **crossing over** can occur.
Metaphase I		• Homologous chromosomes align at the equator.
Anaphase I		• Paired homologous chromosomes separate from each other and are pulled to opposite ends of the cell by the spindle fibres.
Telophase I		• The cell membrane pinches in. • The nuclear membranes re-form. • Two separate nuclei form.
Cytokinesis (after meiosis I)		• The division of cytoplasm starts. • The cell pinches completely into two haploid (n) daughter cells.
Meiosis II		
Prophase II		• Nuclear membranes disappear. • Spindle fibres re-form in both cells.

Table 2.4 The stages of meiosis I and meiosis II

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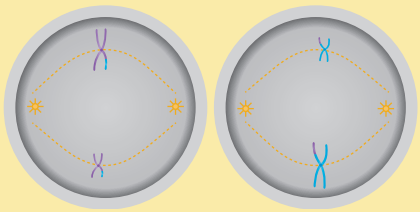
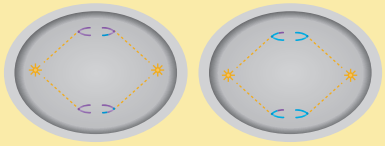
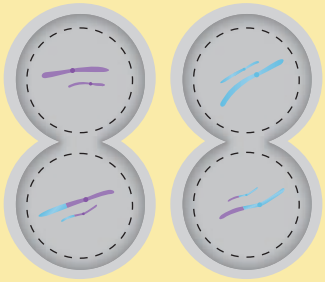
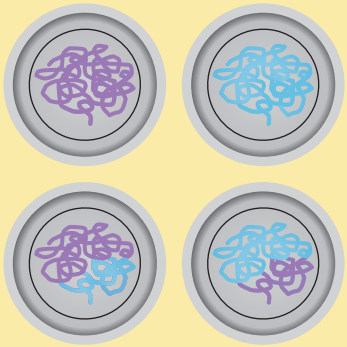
Metaphase II		• Chromosomes line up at the equator.
Anaphase II		• The chromosomes are pulled apart, separating the sister chromatids, which are pulled to opposite sides of the cell. • The spindle fibres disappear.
Telophase II		• The nuclear membrane re-forms. • The chromosomes start to become less visible.
Cytokinesis 4 × *n* (after meiosis II)		• The division of cytoplasm starts. • The cells produce four genetically different haploid daughter cells (*n*), each containing half the amount of DNA that was in the parent cell.

Table 2.4 *(continued)*

Did you know? 2.4

Creating variation

Crossing over can occur in prophase I of meiosis I when homologous chromosomes get so close together that some of their genetic material gets exchanged. It results in the chromosomes recombining to form a new combination of **alleles**, increasing the diversity of a species and therefore increasing its ability to respond to changing environments over time. This is how meiosis can increase genetic variation.

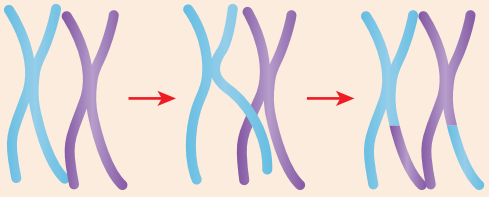


Figure 2.19 Recombination occurs when homologous chromosomes undergo crossing over in prophase I.

allele
a different form of the same gene

recombination
the rearrangement of genetic material, especially by crossing over

Quick check 2.8

1. **Describe** why the process of meiosis is also known as 'reduction' cell division.
2. **Recall** where meiosis occurs in humans.
3. **Explain** why crossing over is an important process during meiosis.

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Fertilisation

fertilisation the fusion of male and female gametes to form a zygote

stem cells undifferentiated cells with the ability to develop into various specialised cell types

In humans, **fertilisation** occurs when two haploid gametes fuse to form a diploid zygote. For fertilisation to occur, the sperm must complete the acrosome reaction. The acrosome is a structure, located in the head of the sperm, that is filled with enzymes. These enzymes are released to digest their way through the corona radiata and zona pellucida, the outer layers of the ovum. Once the sperm penetrate these layers, the cell membranes of one of the sperm cells and the ovum fuse together, and the sperm nucleus can enter the ovum. The fusing of cell membranes also triggers a reaction that causes the zona pellucida to harden. This is called the cortical reaction, and ensures that only one sperm fertilises the egg, preventing polyspermy, which would lead to an abnormal number of chromosomes and non-viable embryos.

Stem cells

Zygote will develop into an embryo, which initially consists of **stem cells**. These cells are undifferentiated and have the potential to become any cell type if removed from the embryo. As the embryo grows, the stem cells can differentiate into specialised cells that form various tissues and organs. These embryonic stem cells, derived from early embryos, can differentiate into a wide range of cell types but are challenging to obtain.

In contrast, adult stem cells, found in specific body tissues like bone marrow and skin, have a more limited differentiation potential but are more accessible. Stem cells hold significant promise for medical treatments, including replacing damaged cells in conditions like type 1 diabetes and spinal cord injuries.

Explore! 2.3

HeLa cells

HeLa cells are a line of human cancer stem cells that have been widely used in scientific research since their discovery in 1951. These cells originated from a tissue sample taken from Henrietta Lacks, an African American woman diagnosed with cervical cancer. Without her knowledge or consent, cells from her tumour were cultured and found to have the ability to survive and proliferate indefinitely.

Figure 2.20 A statue of Henrietta Lacks in Bristol, England, created by artist Helen Wilson-Roe. The statue was unveiled on the 70th anniversary of Lacks's death.

Find some reliable sources online to complete the following:

1. Investigate the history of HeLa cells, including the story of Henrietta Lacks and the ethical controversies surrounding the use of her cells without consent.
2. Explore various genetic technologies that utilise HeLa cells, such as cancer research, drug development and vaccine production.
3. Choose an ethical framework to guide your analysis (e.g. utilitarianism, deontology, virtue ethics, rights-based, care-based).
4. Reflect on the ethical concerns related to consent, ownership and the use of biological materials.
5. Construct a well-organised written argument that incorporates evidence from your research.
6. Clearly outline your chosen ethical framework and how it applies to the use of HeLa cells.
7. Discuss the ethical implications of continuing to use HeLa cells in genetic research, considering both the benefits and the controversies.

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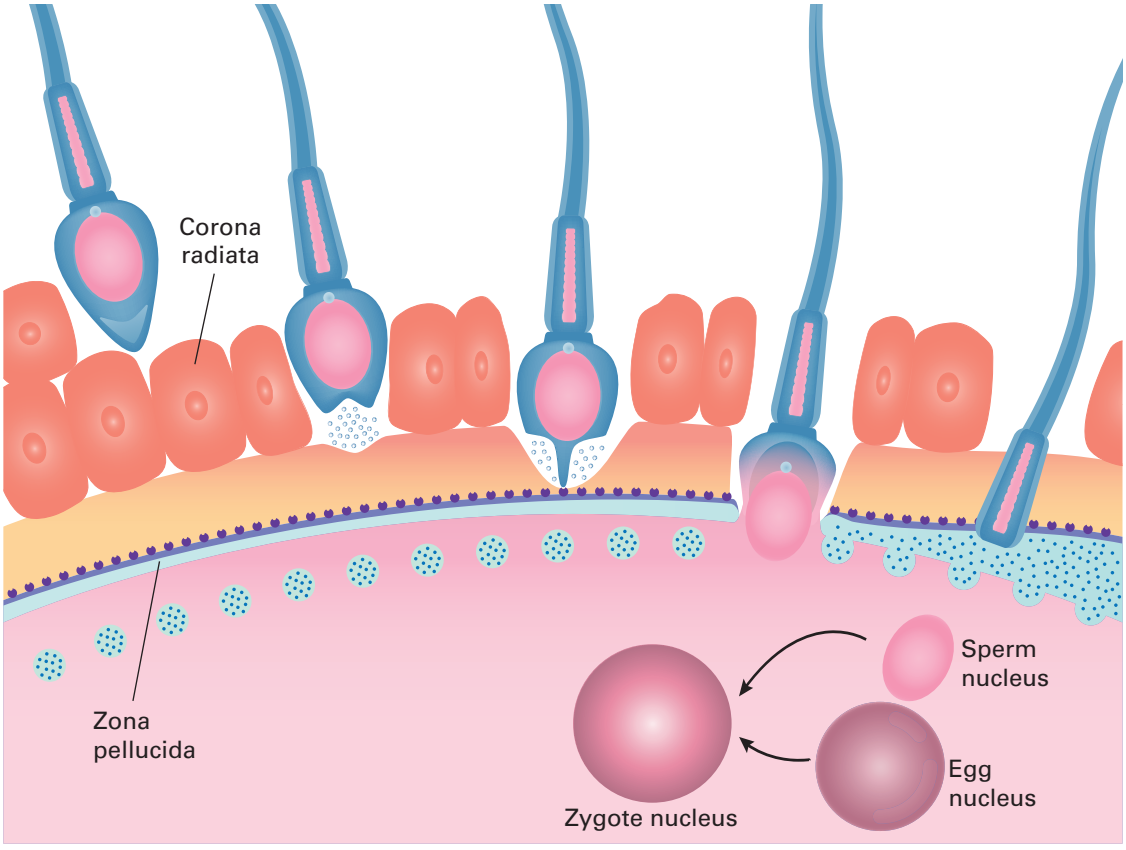

Figure 2.21 Once a sperm fertilises the egg, the nuclei of the sperm and the egg fuse.

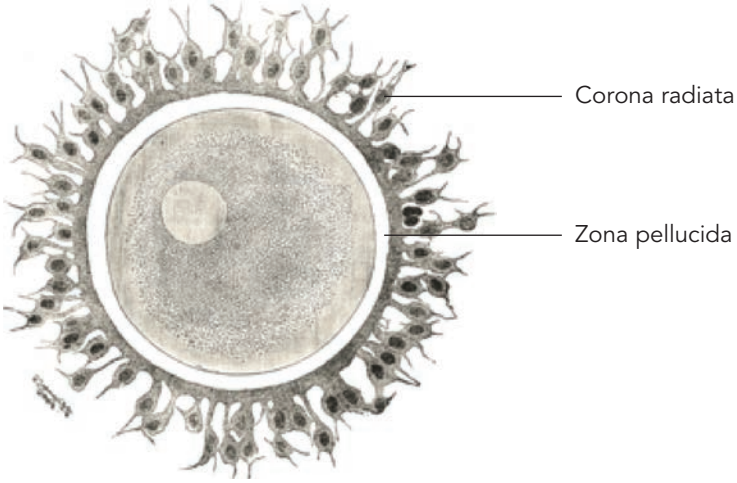

Figure 2.22 A human ovum

Quick check 2.9

1. Copy the table below and **define** the terms.

Term	Definition
Meiosis	
Fertilisation	
Zygote	
Haploid	
Diploid	

2. **Identify** the missing words in the following sentence.
Male gametes are called _____, whereas female gametes are called _____.

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Explore! 2.4

Types of twins

You, or someone you know, might have a twin sister or brother. There are two main types of twins: identical (monozygotic) and fraternal (dizygotic). However, there is another, very rare form of twins known as semi-identical (sesquizygotic). Only two cases have ever been recorded, one in the US and one in South East Queensland. Conduct some research and answer the following questions:

1. Describe how monozygotic and dizygotic twins are formed.
2. Draw a diagram to show how these different types of twins are formed.
3. Discuss why sesquizygotic twins are so rare.

VIDEO
Mitosis and meiosis

Meiosis versus mitosis

Although the processes of meiosis and mitosis have similarities, there are some differences:

- In meiosis, chromosomes recombine by crossing over, producing chromosomes with new combinations of genes. In mitosis, chromosomes are replicated to make identical copies of themselves.
- Meiosis involves two divisions that produce four haploid (n) daughter cells containing unique genetic material that is different to that of the parent cells. Mitosis involves one division that produces two diploid ($2n$) daughter cells with genetic material identical to that of the parent cell.

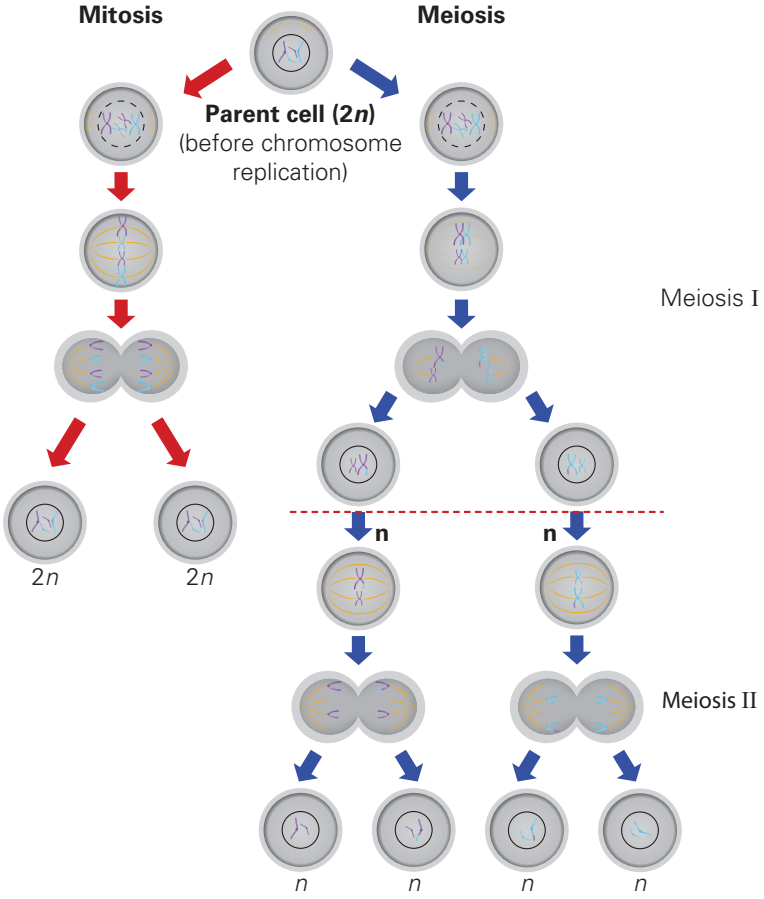

Figure 2.23 A summary of the processes of mitosis and meiosis

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Karyotypes

The number of chromosomes varies between species, but in diploid organisms, chromosomes in body cells are always present in pairs. For example, humans have a total of 46 chromosomes, consisting of 22 pairs of homologous chromosomes and one pair of sex chromosomes in the nucleus of each body cell. However, gametes contain only 23 chromosomes – 22 autosomes and one sex chromosome – ensuring that the correct chromosome number is restored during fertilisation.

Homologous chromosomes are present in body cells because we receive one from each parent. Homologous chromosomes have the same length, centromere position and gene band patterns and are paired together in **karyotypes** (see Figure 2.24). Chromosomes that do not match (chromosomes from different pairs) are called **non-homologous chromosomes**.

karyotype the chromosomes of an individual, often displayed according to size and gene band patterns

non-homologous chromosomes chromosomes that do not belong to the same pair

autosome any chromosome that is not a sex chromosome; in humans, these are chromosome pairs 1 to 22

sex chromosomes chromosomes that determine the sex of an organism

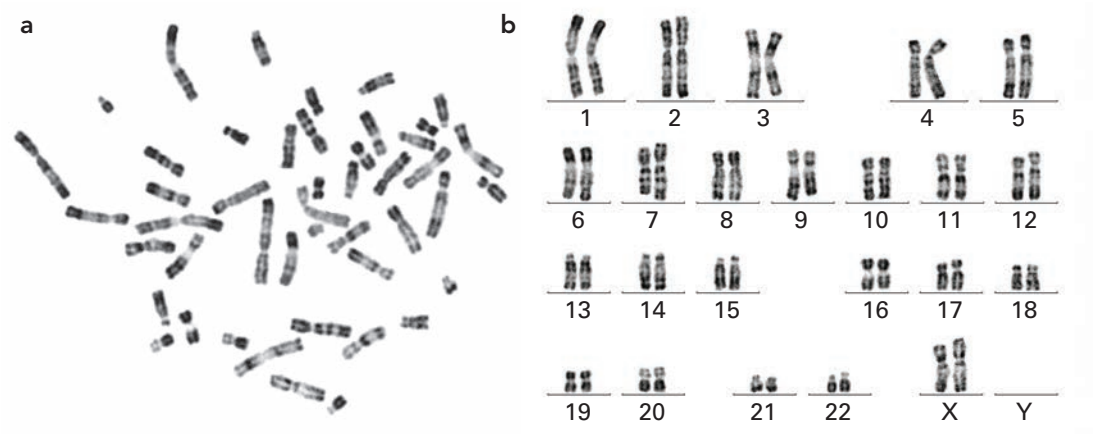

Figure 2.24 (a) The homologous chromosomes seen under a microscope **(b)** can be arranged according to size in a karyotype. Pairs 1–22 are autosomes, while pair 23 is the sex chromosomes. The presence of two X chromosomes indicates this is a karyotype from a female.

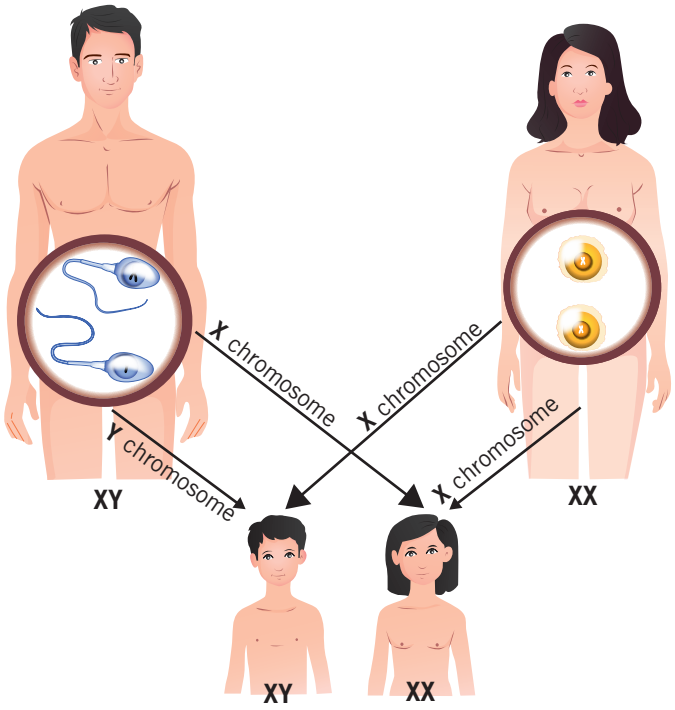

Figure 2.25 If an egg is fertilised by a sperm carrying an X chromosome, the child will be female. If an egg is fertilised by a sperm carrying a Y chromosome, the child will be male. Therefore, it is the male's sperm that determines the sex of the child.

Autosomes

Of the 23 pairs of chromosomes in humans, pairs 1 to 22 are known as **autosomes**. These 44 chromosomes are found in both males and females.

Sex chromosomes

In humans, the chromosomes making up the 23rd pair are the **sex chromosomes**. They contain genes that determine the sex of the individual. Females receive two X chromosomes (one from each parent), whereas males receive an X chromosome from the mother and a Y chromosome from the father (see Figure 2.25).

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Practical 2.3

What are the chances?

Aim

To investigate the chances of conceiving a male or female at fertilisation.

Useful formulas

$$\text{Theoretical probability (\%)} = \frac{\text{number of a particular outcome (e.g. heads)}}{\text{total number of all possible outcomes (e.g. heads and tails)}} \times 100$$

$$\text{Experimental probability (\%)} = \frac{\text{number of a particular outcome (e.g. heads)}}{\text{total number of all experimental trials (e.g. heads and tails)}} \times 100$$

$$\text{Percentage error (\%)} = \frac{(\text{experimental probability} - \text{theoretical probability})}{\text{theoretical probability}} \times 100$$

Materials

- one coin

Method

1. Copy the results table into your science book.
2. Calculate the theoretical probability of landing heads during a toss.
3. You will now calculate the experimental probability of your own experiment by tossing the coin 50 times, recording the number of heads and tails in the table.

Results

1. Calculate the experimental probability of receiving a head and a tail based on both your own data and the class data.
2. Calculate the percentage error, comparing the difference between the theoretical and experimental probabilities for both your own data and the class data.
3. Optional: Graph the relationships between the number of trials and percentage error.

	Individual results	Class results
Number of heads		
Number of tails		
Total number of trials (throws)		
Experimental probability		
Percentage error		

Discussion

1. Compare your own experimental probabilities with the class results.
2. If a head represents the Y chromosome and a tail represents the X chromosome, explain how accurately this models the process of fertilisation. What would the coin represent?
3. Make a claim about the chances of conceiving a male or female based on this activity.
4. Discuss whether increasing the number of trials affects the percentage error of the experiment.

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Did you know? 2.5

Sex chromosomes in the animal kingdom

In some animals, such as birds, females have two different sex chromosomes (ZW) while males have two of the same (ZZ). In some reptiles, the temperature of the incubating environment determines the sex of the embryo. In some insects, females are XX and males have one X chromosome (written XO).

Monotremes have a complex sex chromosome system. Female platypuses have five pairs of X chromosomes and males five X and five Y chromosomes. Female echidnas have five pairs of X chromosomes and males five X and four Y chromosomes.

Figure 2.26 Female platypuses have five pairs of X chromosomes.

Try this 2.3

Can you sort chromosomes into a karyotype?

Go online and find a karyotype activity. There are many interactives that allow you to sort chromosomes into order and ones that allow you to analyse karyotypes.

Science inquiry 2.1

Genetic testing

When a person is pregnant, their doctor may conduct several tests to screen for genetic and chromosomal abnormalities in the foetus. Creating a karyotype lets the doctor check for abnormalities in the number or length of chromosomes. If anything appears abnormal, the doctor can undertake further genetic tests to check for specific disorders. One such test is chromosomal microarray (CMA) testing, which is much more detailed genetic testing than karyotyping. Chromosomal microarray testing detects around one abnormality in every 70 foetal samples with a normal karyotype. Scientists think that CMA testing will replace karyotyping for prenatal testing.

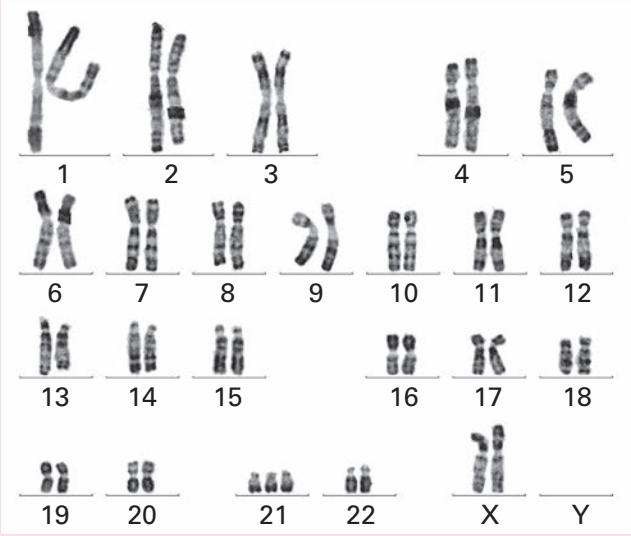

Figure 2.27 A well-known chromosomal abnormality is trisomy 21 or Down syndrome, where the foetus has three copies (instead of two) of chromosome 21.

continued …

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Genetic testing will identify carriers of genetic mutations and help people make informed decisions, such as in embryo selection. Genetic counsellors work with people who are concerned about having, or have been diagnosed with, a genetic condition.

Many people are also having genetic testing to discover more information about their ancestry or to connect with unknown relatives. Although it is against the law to be discriminated against because of genetic information, there is some concern regarding its use, either personally or by organisations such as insurance companies or medical facilities.

Have a class discussion regarding the ethical issues of non-therapeutic genetic testing performed by commercial companies. You may want to consider privacy concerns, the possible emotional impact, potential lack of medical knowledge and possible exploitation of vulnerable individuals.

Asexual reproduction

Asexual reproduction is a mode of reproduction in which a single parent produces offspring that are genetically identical to itself, meaning they are clones of the parent organism. Unlike sexual reproduction, which requires the combination of genetic material from two parents, asexual reproduction doesn't involve gametes or fertilisation.

There are various forms of asexual reproduction, each suited to different organisms:

- Binary fission: Common in single-celled organisms like bacteria, where the cell divides into two, each becoming an identical organism.
- Budding: Seen in organisms like yeast and hydra, where a new individual grows off the parent organism and eventually detaches to live independently.
- Fragmentation: Certain animals, like starfish and some plants, can grow into a complete organism from a fragment of the parent's body.
- Vegetative propagation: In plants, new individuals grow from stems, roots or leaves. Examples include strawberry runners and potato tubers.
- Spore formation: Many fungi, algae and some plants reproduce through spores, small structures that develop into new organisms without fertilisation.
- Parthenogenesis: Found in some reptiles, insects and fish, where an egg cell develops into a new organism without fertilisation, producing offspring genetically similar to the mother.

Figure 2.28 Budding hydra

Figure 2.29 Vegetative propagation

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A key advantage of asexual reproduction is its efficiency; organisms can reproduce quickly and in stable environments, allowing populations to grow rapidly. However, because offspring are genetically identical to the parent, there is less genetic variation, which can make the population vulnerable to diseases and changing environmental conditions.

Quick check 2.10

1. **Compare** mitosis and meiosis using a Venn diagram.
2. **Explain** what karyotypes can show and why this is useful.

Section 2.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 2.2 questions

Remembering

1. **State** one key difference between mitosis and meiosis.
2. **Recall** the phase of meiosis when pairs of matching chromosomes separate.
3. **State** the name of the syndrome that arises from trisomy 21.
4. **State** what the term 'homologous chromosomes' means.

Understanding

5. **Explain** why gametes need to be haploid.
6. **Explain** what is meant by the term 'reduction division'.
7. **Explain** why a chromosome missing a part may lead to a disorder or syndrome.
8. **Explain** why the cells produced during meiosis are genetically unique.

Applying

9. Complete the following table to **differentiate** between mitosis and meiosis.

	Where it occurs	Purpose	Features of daughter cells
Mitosis			
Meiosis			

10. **Contrast** the daughter cells produced in mitosis versus meiosis.
11. **Illustrate** a diagram to represent the steps of mitosis for a cell with two pairs of chromosomes. Be sure to use a different colour for each pair of chromosomes.

Analysing

12. **Contrast** anaphase I in meiosis and anaphase in mitosis.
13. **Contrast** prophase I and prophase II in meiosis.

Evaluating

14. **Critique** the following claim: It is the male that determines the sex of the child.
15. **Predict** the chances of a woman giving birth to a girl if she has already given birth to three boys, giving reasons for your response.

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2.3 Patterns of inheritance

Learning goals

At the end of this section, I will be able to:

1. Define the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive' with respect to genetic inheritance.
2. Use and interpret Punnett squares to identify possible genotypes and phenotypes of offspring.
3. Use pedigree diagrams to determine the type of inheritance that is occurring.
4. Explain codominance, incomplete dominance and sex linkage.

Figure 2.30 This artwork from Kakadu National Park shows Namondjok, a Creation ancestor who broke kinship laws.

Aboriginal and Torres Strait Islander communities have understood inheritance patterns for a long time. They recognise how traits can be passed down to the next generation and how negative traits and illnesses often appear in the children of closely related parents. Because of this deep knowledge, communities created complex and sophisticated kinship systems which allow individuals to understand who they are and how they fit into the social structure and even the universe. These kinship systems are strictly adhered to and dictate who can or cannot marry through marriage laws. Kinship and family structures also determine how individuals behave towards others and the responsibilities each person has towards others, natural resources and the land. For example, a person may be obliged to care for their sibling's offspring. These children usually address their aunt or uncle as 'mother' or 'father' and their cousins as 'brothers' or 'sisters'. Although they are aware of their biological parents, the societal (kinship) laws assign equal importance to other relatives. When conversing with one another, Aboriginal and Torres Strait Islander people usually speak Aboriginal English and frequently use the terms 'brother' or 'sister', which are derived from the kinship terminology and connections.

Inheriting traits from our parents

This cultural understanding of inheritance is reflected in modern genetics. Inheriting traits from our parents is now known to be governed by genes – specific sections of DNA passed from parent to offspring. Each characteristic or trait that we inherit is controlled by one or more pairs of genes. Members of each gene pair are found at the same location on their respective homologous chromosomes. This is called the **locus** of a gene.

locus (plural: loci) the location of a gene on a chromosome

Genes are sections of DNA that code for a particular protein that contributes to our characteristics, such as a gene for eye colour. However, not all forms of a gene are the same; for example, different people can have different eye colours. We use the term 'allele' to describe the different forms of a gene.

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We get one copy of each chromosome from each parent, resulting in us inheriting one copy of each gene from each parent. The combination of alleles an organism has for a particular gene is known as the organism's **genotype**. If two identical alleles are present in a person's genotype, they are known as **homozygous** for that particular trait. However, if there are two different alleles present for the same trait, then the person is **heterozygous** for that trait.

For example, consider the trait of freckles. This trait is controlled by a single gene that is represented using two alleles. The allele of the dominant trait is the presence of freckles (we assign it the capital letter 'F' to show that it represents the dominant trait), and the allele for the recessive trait is the lack of freckles (assigned a lower case 'f' to show that it represents the recessive trait). A trait or characteristic is described as **dominant** if you need only one allele for it to be expressed (FF or Ff). For a **recessive** characteristic, the allele needs to be inherited from both parents for it to be expressed (ff).

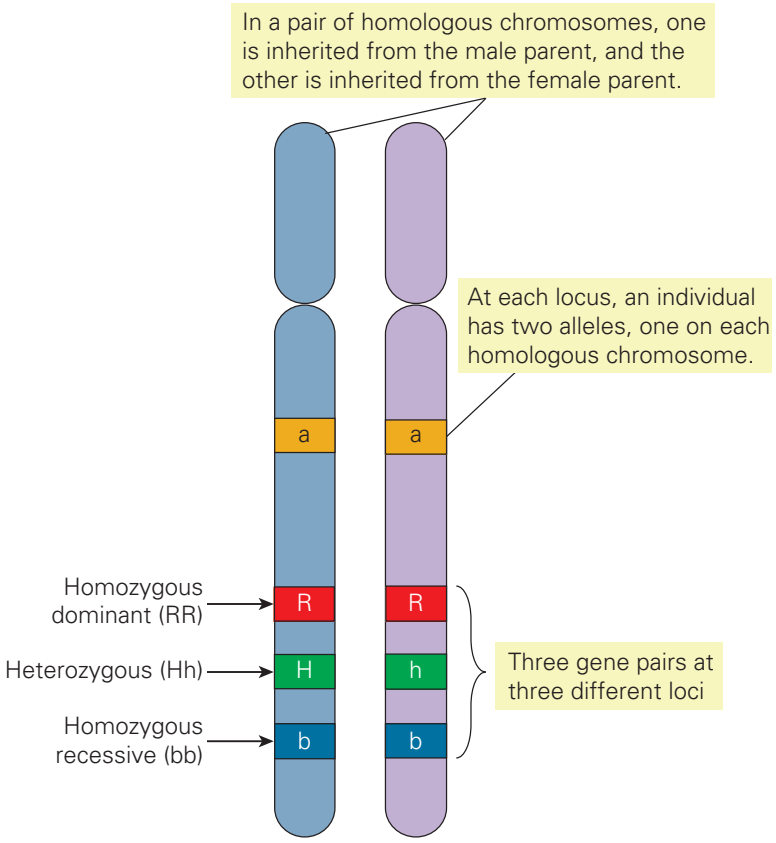
In a pair of homologous chromosomes, one is inherited from the male parent, and the other is inherited from the female parent.
At each locus, an individual has two alleles, one on each homologous chromosome.
a
a
Homozygous dominant (RR)
R
R
Heterozygous (Hh)
H
h
Homozygous recessive (bb)
b
b
Three gene pairs at three different loci

Figure 2.31 Gene loci on homologous chromosomes

Did you know? 2.6

The genome

The **genome** refers to all the genetic material in the chromosomes of an organism, including its genes and DNA sequences. The human genome is made of approximately 3.2 billion nitrogenous base pairs, which make up about 20 000 genes on 23 pairs of chromosomes. Other organisms have different genome sizes. Surprisingly, only a small percentage of the genome, around 1–2%, contains genes that code for proteins; the vast majority of the genome is made up of non-coding DNA, which does not directly code for proteins, although it can still play important roles in gene regulation and other cellular functions.

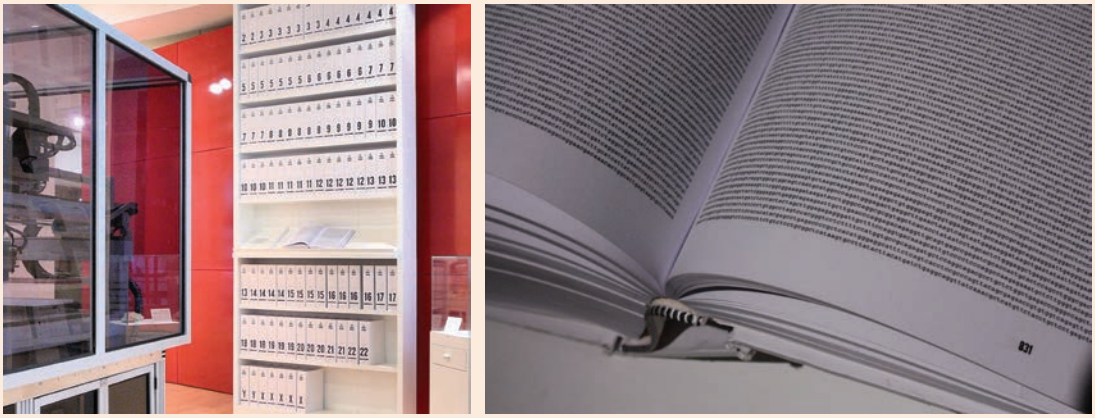

Figure 2.32 The first publication of the human genome was printed as 109 books in 23 volumes. The around three billion units of human DNA code are printed in a small font, and each book is a thousand pages long.

genotype
the combination of alleles an organism has for a particular gene

homozygous
having two identical alleles at a particular gene locus

heterozygous
having two different alleles at a particular gene locus

dominant
a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

recessive
a characteristic in which the allele responsible is only expressed in the phenotype if two copies of the allele are present

genome
the complete set of genetic material in an organism

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Figure 2.33 The presence of freckles is an example of a dominant trait.

If you inherit the freckles allele from both parents, you are homozygous dominant for that trait and your genotype will be FF. If you inherit the no-freckles allele from both parents, you are homozygous recessive for that trait and your genotype will be ff. If you inherit a freckles allele from one parent and a no-freckles allele from the other parent, you are heterozygous for that trait and your genotype will be Ff.

The interaction of an organism's genotype with the environment results in its **phenotype**, or its physical appearance. Typically, multiple genes and multiple environmental factors interact in the development of most traits. In the example in Figure 2.33, the presence of freckles is the person's phenotype for that trait. The freckles are present due to the person's genotype and their environmental exposure to UV light.

phenotype the observable characteristics of an organism, resulting from both genotype and the environment

To determine whether an allele represents a trait that is dominant or recessive, scientists look at the phenotype of a heterozygous organism. If the trait is expressed in this phenotype, it must be the dominant trait.

Quick check 2.11

1. Copy the table below and **define** the terms.

Term	Definition
Locus	
Allele	
Genotype	
Phenotype	
Dominant	
Recessive	
Heterozygous	
Homozygous dominant	
Homozygous recessive	

2. **Explain** why a genotype can indicate that a person will have freckles, but there are not many on their face.

Practical 2.4

Inherited features

Aim

To use data to determine whether some key characteristics are dominant or recessive traits.

Materials

- mirror

Optional extension: Collect information from other students or family members for further validity analysis.

continued …

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Method

Part 1: Prepare the results table

1. Copy the results table into your science book.

Part 2: Collect data on the variables

1. Identify whether you possess each of the inheritable features described below.
2. Record your results in the table.
3. Find out how many members of your class share the same features as you do. Record your results in the table. Optional: Find out how many members of your family display the traits.
   - **a)** Attached ear lobes: are your earlobes attached or unattached to the side of your head?
   - **b)** Widow's peak: do you have a V-shaped peak in the centre of your hairline as shown in Figure 2.34?
   - **c)** Tongue roll: can you roll your tongue as shown in Figure 2.35?
   - **d)** Front-tooth gap (diastema): is there a definite gap between your two top front teeth as shown in Figure 2.36?
   - **e)** Mid-digital hair: is there any hair on the second joint of at least one of your fingers?
   - **f)** Long second toe: is your second toe longer than your big toe as shown in Figure 2.37?

Figure 2.34 This girl has a widow's peak (V-shaped peak) in the centre of her hairline.

Figure 2.35 This woman is able to roll her tongue.

Figure 2.36 This man has an obvious gap between his top front teeth.

Figure 2.37 The second toe is longer than the big toe on this foot.

Results

1. Calculate the total number of people sampled in this survey.
2. Calculate the percentage presence of the trait in your family and within the class.
3. Draw an appropriate graph (or graphs) to compare the percentage presence of each trait within your family with the percentage presence in the whole class.

Feature	Trait present in you? (Y/N)	Number of family members with trait	Presence of trait in family (%)	Number of class members with trait	Presence of trait in class (%)	Presence of trait in total sample (%)
Attached ear lobes						
Widow's peak						
Tongue roll						
Diastema						
Mid-digital hair						
Long second toe						
Sample size (*Total number of people surveyed*)	1					

continued …

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Discussion

1. Describe which traits were commonly found in your family.
2. Describe which traits were commonly found in the class.
3. Describe which traits were commonly found in the whole sample.
4. Do your findings support the idea that a feature such as tongue-rolling is inherited? Explain your answer.
5. Predict from the data which traits are likely to be recessive and dominant. Justify your answer with data.
6. If you repeated the survey on the same people, would you get a similar result? Support your answer, relating back to the theory behind inheritance of traits.
7. Can reliable conclusions and predictions be drawn from the results?
8. Compare the values from your family with those from the class. Were there any significant differences with some traits? Justify your answer with data.
9. Compare the values from your family with results from several other students' families. Were there any significant differences with some traits? Justify your answer with data.
10. Can you draw valid conclusions as to which traits are dominant and recessive from this data? Justify your response.
11. Sample size is a factor that commonly affects data in small surveys. Discuss how this relates to the activity.
12. Can you identify possible limitations of this method? Justify your answer.
13. Suggest any changes that could be made to the method to improve the quality of the data in future surveys. Justify your suggestions by explaining how each change will improve the data quality.

WORKSHEET
Inheritance

Determining chances of inheritance

Gregor Mendel

Gregor Mendel is known as the father of genetics. Born in 1822, he was an Austrian monk who carried out experiments in his garden using pea plants and discovered some of the fundamental laws of heredity we still rely on today.

Mendel looked at the features of pea plants, which could be tall or short (dwarf). He assigned the following letters to represent these alternative characteristics (known today as alleles): T = tall and t = dwarf. Mendel bred the plants and observed the height of the plants in the next generation. He discovered that tall pea plants could be either pure-breeding (TT or homozygous dominant) or hybrid (Tt or heterozygous). The dwarf plants could only be tt (homozygous recessive). Today, we call this the plant's genotype.

Mendel also used the following notation to represent different levels of generations:

- P = parent generation
- F_1 = first **filial** generation (first generation of offspring)
- F_2 = second filial generation (second generation of offspring).

filial
describes the offspring of a cross

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An easy way to predict the outcome of **monogenic** traits is to use a **Punnett square**, a specialised grid invented by Reginald Punnett. A Punnett square is a visual representation of a **monohybrid cross**, which is a breeding experiment involving two individuals that differ in a trait of interest. In a monohybrid cross, the parents are typically represented by letters to denote their respective alleles for the trait being studied.

Figure 2.38 Gregor Johann Mendel was the founder of the science of genetics, using pea plants to show dominant and recessive traits. He produced large amounts of data which all supported his theory, but later statistical analysis suggests that he may have falsified his data – it was simply too good to be true! Large data sets and statistical analyses are vital for validating scientific findings.

monogenic
a trait that is controlled by a single gene

Punnett square
a specialised grid to show genetic crosses

monohybrid cross
a type of genetic cross or breeding experiment that considers the inheritance of a single trait or characteristic that is typically controlled by a single gene with two alleles

To use a Punnett square, you need to know the genotype of the parents to work out what genetic information they could pass on to their offspring via the gametes. For example, we know a heterozygous tall pea plant has the genotype Tt. This means that when the plant makes its gametes, they could contain either a T or a t, as gametes only carry one of the alleles from the parent. In contrast, a homozygous tall pea plant has the genotype TT, so its gametes will all contain a T.

Worked example 2.1

Cross between a pure-breeding tall plant and a pure-breeding dwarf plant

Parents: TT × tt

Gametes	T	T
t	Tt	Tt
t	Tt	Tt

You will notice that all the predicted F_1 offspring (shaded) have the genotype Tt. We can write this as:

F_1 genotype: 100% Tt

We can also see that offspring with Tt would all physically appear tall, as T stands for the tall allele. The tall trait is dominant over the dwarf trait, which is encoded for by the t allele. So, we can write this as:

F_1 phenotype: 100% tall plants

Worked example 2.2

Cross between two of the hybrid F_1 plants from Worked example 2.1

F_1: Tt × Tt

Gametes	T	t
T	TT	Tt
t	Tt	tt

F_2 genotype: 25% TT; 50% Tt; 25% tt

F_2 phenotype: 75% tall plants; 25% dwarf plants

We can also write the predicted outcomes as ratios. In this case, when two heterozygous tall pea plants were crossed, there was a genotypic ratio of 1TT : 2Tt : 1tt and a phenotypic ratio of 3 tall : 1 dwarf.

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Choosing letters for genetic notation

When selecting letters to represent alleles, it is important to choose ones that are easily distinguishable in both uppercase and lowercase forms. Avoid letters that look similar in both cases, as this can cause confusion when reading genotypes.

Letters to avoid using include c, s, w, o, v and x.

Huntington's disease

Huntington's disease is inherited as a dominant trait on an autosome. It usually appears in an affected person as neurological symptoms that develop around 30–50 years of age. These symptoms result from an abnormal protein being made.

If we let H = abnormal Huntington's protein allele (Huntington's disease) and h = 'normal' protein allele (unaffected), then we can use these notations to help work out probable outcomes in the offspring.

Worked example 2.3

Cross between two individuals unaffected by Huntington's disease

Parents: hh × hh

Gametes	h	h
h	hh	hh
h	hh	hh

F_1 genotype: 100% hh

F_1 phenotype: 100% unaffected

Worked example 2.4

Cross between an individual with Huntington's disease and an unaffected individual

Parents: Hh × hh (Having two H alleles is extremely rare, so we will assume the individual with Huntington's disease is Hh).

Gametes	H	h
h	Hh	hh
h	Hh	hh

F_1 genotype: 50% Hh; 50% hh

F_1 phenotype: 50% with Huntington's disease; 50% unaffected

Try this 2.4

Punnett squares

1. A black mouse mates with a brown mouse. There is a large number of offspring and all of them are black.
   a) Which trait is dominant?
   b) Draw a Punnett square and determine the genotypes of the offspring.
2. An allele of a particular gene causes a recessive condition called cystic fibrosis. If a homozygous recessive individual has a child with a heterozygous individual, what are their chances of producing offspring with cystic fibrosis?

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Quick check 2.12

1. **Contrast** genotype and phenotype.
2. Brown eyes are dominant over blue eyes.
   a) **Select** letters for the brown eye and blue eye alleles.
   b) **Create** a Punnett square for a couple who are both heterozygous.
   c) **State** the genotypic and phenotypic ratios of the offspring.
   d) **State** the chances of this couple producing a blue-eyed child.

Test cross

A **test cross** can be used to discover whether an organism showing a dominant trait is homozygous dominant or heterozygous. It involves observing the offspring of the individual in question if it mates with a homozygous recessive individual (for example, aa). This means the individual of unknown genotype mates with an individual of known genotype. By looking at the offspring ratio, we can deduce the unknown genotype of the individual in question.

test cross
a genetic cross between a homozygous recessive individual and an individual of unknown genotype showing the dominant trait to determine the unknown genotype

For example, in guinea pigs, coat colour may be black (B) or white (b). You can find out if a black guinea pig is homozygous black (BB) or heterozygous black (Bb) by doing a test cross between the black guinea pig and a white guinea pig (bb).

If the unknown black guinea pig is BB, the cross would look like this:

Parents: BB × bb

Gametes	B	B
b	Bb	Bb
b	Bb	Bb

F_1 genotype: 100% Bb

F_1 phenotype: 100% black

This means if all the offspring are black, the unknown black guinea pig is probably BB (or homozygous dominant).

If the unknown black guinea pig is Bb, the cross would look like this:

Parents: Bb × bb

Gametes	B	b
b	Bb	bb
b	Bb	bb

F_1 genotype: 50% Bb; 50% bb

F_1 phenotype: 50% black; 50% white

This means if roughly half the offspring are black and half are white, the unknown black guinea pig is probably Bb (or heterozygous). Note that these expectations are only true when based on large numbers of offspring because they are probabilities. However, if even one white offspring is born, the black guinea pig must be heterozygous in order to have passed on a b allele.

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Worked example 2.5

Determining the genotype of a dominant parent

A breeder is investigating the inheritance of a dominant trait in rabbits, controlled by a single gene. Allele B codes for black fur, which is dominant, and allele b codes for white fur, which is recessive. The breeder crosses a black-furred rabbit with a white-furred rabbit and records the following offspring:

Fur colour	Number of offspring
Black	24
White	26

Based on this data, determine whether the black-furred parent is homozygous dominant (BB) or heterozygous (Bb).

Step 1: Predict offspring ratios

Working

If the parent is homozygous dominant (BB):

Cross: BB × bb

Gametes	B	B
b	Bb	Bb
b	Bb	Bb

F1 phenotype: 100% black-furred

Explanation

Since the white-furred trait is recessive, we already know that the white-furred parent is homozygous (bb). If the black-furred parent is homozygous dominant (BB), all offspring would inherit one B allele, making them 100% black-furred (Bb).

Working

If the parent is heterozygous (Bb):

Cross: Bb × bb

Gametes	B	b
b	Bb	bb
b	Bb	bb

F_1 phenotype: 50% black-furred; 50% white-furred

Explanation

If the black-furred parent is heterozygous (Bb), the offspring would be in a 1:1 ratio of black-furred (Bb) to white-furred (bb).

Step 2: Compare with observed data

Black-furred parent genotype: heterozygous (Bb).

The breeder observed:

- 24 black-furred rabbits
- 26 white-furred rabbits.

This is very close to a 1:1 ratio, which matches the expected outcome of a heterozygous (Bb) × homozygous recessive (bb) cross. Since a homozygous dominant (BB) parent would not produce white-furred offspring, the data strongly suggests that the black-furred parent is heterozygous (Bb).

Quick check 2.13

1. **Explain** the importance of a test cross.
2. In a bird species, normal feathers are a dominant trait, and silky feathers are a recessive trait. Both traits are coded for by alleles of the same gene. If you had a normal-feathered bird, **describe** a way to determine whether it is heterozygous or homozygous. Use Punnett squares to help with your answer.

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Try this 2.5

Positive or negative

One vital gene located on chromosome 1 in humans is the gene controlling for Rhesus (Rh) blood type. Rh-positive blood is dominant to Rh-negative blood, so we can assign the alleles D (Rh-positive) and d (Rh-negative). Therefore, an Rh-positive person can be either DD or Dd with respect to this gene, but an Rh-negative person can only be homozygous, dd.

Method

In this activity, we will use coloured counters and felt-tipped pens to model the passing of Rh alleles from heterozygous individuals to their offspring.

1. Copy the results table into your science book.
2. Choose one coloured counter. Print D on one side and d on the other to represent the alleles of the chromosomes. This counter represents an individual who is Dd for Rh blood type. That is, they are able to produce gametes (eggs or sperm) of the type D and d in equal proportions.
3. Find a partner in the room with a different-coloured counter.
4. Make an unbiased toss of your two counters to produce an offspring. The labels facing up on the counters will represent the alleles of the gametes produced by the parents. Record the genotype of the offspring in the Family 1 row of the following table. Repeat this step three more times to produce a total of four children.
5. Generate a total of four families (by pairing up with three different students) with each having produced four children.
6. Record the number of each type of genotype found in the children of each family in the table following table. Pool your total results with those of the class.

Results

	Genotype of children		
	DD	**Dd**	**dd**
Family 1			
Family 2			
Family 3			
Family 4			
Total numbers across the class			

Discussion

1. Using the class data, calculate the probability of obtaining the offspring genotypes:
   a) DD
   b) Dd
   c) dd
2. What are the proportions of the different genotypes in your group of 16 children compared to those generated across the whole class? Discuss whether this is expected.
3. A woman with Rh-positive blood insisted that she was the daughter of a rich, elderly couple who both had Rh-negative blood. Use a Punnett square to show your working out to explain whether this woman's statement could be valid.

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Did you know? 2.7

Multifactorial inheritance

Most traits in organisms are shaped through interactions between multiple genes and a range of environmental factors. This concept, known as multifactorial inheritance, recognises that genes don't work in isolation. Instead, different genes may each contribute small effects that, when combined, influence traits like height, skin colour, and even the risk of developing certain diseases. These genetic contributions are then influenced by various environmental factors – such as diet, lifestyle, climate and exposure to toxins – which can further modify trait expression.

For example, height is determined by numerous genes that each play a role in growth, bone structure and metabolism. However, factors like nutrition during childhood and adolescent development also significantly impact height, showing that genes set a potential range, while the environment helps determine where an individual falls within that range.

Sex linkage

As we have seen, in humans the sex chromosomes are the 23rd pair. Human females are homogametic for the X chromosome while males are heterogametic, with one X and one Y chromosome.

The X chromosome also contains many genes that are not related to sex determination (in contrast, the Y chromosome has very few). Characteristics that are not related to determining the sex of the individual but are coded for by X chromosome genes are termed 'X-linked'. When we predict X-linked traits using a Punnett square, we must use the sex chromosomes and superscripted letters above the X chromosomes to represent the trait.

carrier
an individual with an allele for a recessive condition but who does not have the condition due to being heterozygous

For example, Duchenne muscular dystrophy (DMD), a disorder where the muscles progressively degenerate, is inherited as an X-linked recessive trait. The genotype for an unaffected female would be X^DX^D, a **carrier** female (who has an allele for the disease but is heterozygous and so does not have the disease) would be X^DX^d, and a female with DMD would be X^dX^d. On the other hand, an unaffected male would be X^DY, and a male with DMD would be X^dY. As there is no gene for this condition found on the Y chromosome, we do not write ^{D} or ^{d} next to the Y. Because males have only a single copy of the X chromosome, they are more likely to be affected by sex-linked disorders. A single allele of a mutated gene on an X chromosome will cause the disease in a male but not in a female (who would need two DMD alleles to be affected).

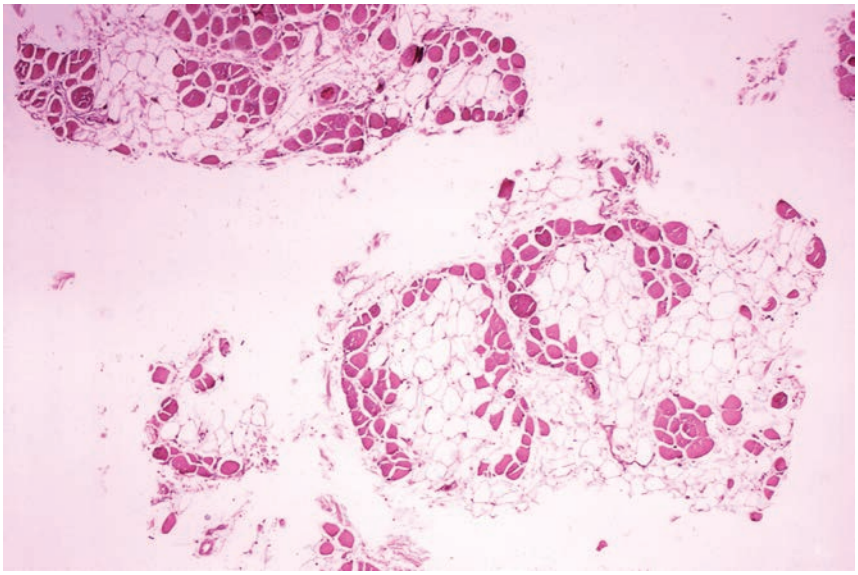

Figure 2.39 In Duchenne muscular dystrophy, muscle fibres (red) are replaced by fat cells (white).

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Worked example 2.6

Cross between a heterozygous normal-vision female (carrier) and a normal-vision male

Colour blindness is inherited as an X-linked recessive trait. The genotype of a heterozygous normal-vision (carrier) female is X^BX^b, and the genotype of a colour-blind male is X^bY.

Parents: $X^BX^b \times X^BY$

Gametes	X^B	X^b
X^B	X^BX^B	X^BX^b
Y	X^BY	X^bY

F_1 genotype: 25% X^BX^B; 25% X^BY; 25% X^BX^b; 25% X^bY

F_1 phenotype: 25% normal-vision female; 25% normal-vision male; 25% carrier normal-vision female; 25% colour-blind male

Try this 2.6

Sex-linked inheritance

Now it is your turn to practise. Remember that the gametes need to include the sex chromosomes, and the genotype and phenotype both need to include the sex chromosomes as well.

1. Using a Punnett square, cross a normal-vision female (homozygote) with a colour-blind male.
2. Using a Punnett square, cross a colour-blind female with a normal-vision male.
3. Explain why more males than females have colour blindness.

Codominance

Codominance occurs when two alleles are expressed equally in the phenotype of a heterozygote. This is **codominance**. Look at the picture of the chickens in Figure 2.40. The colours black and white are equally dominant (their alleles are given two different capital letters), so when you cross a pure black chicken with a pure white chicken, you get a heterozygote. In the heterozygote, both colours are expressed equally, so you get a speckled chicken with black feathers and white feathers!

VIDEO
An example of codominance

codominance
both alleles are expressed equally in the phenotype

Genotype	WW	BB	BW
Phenotype	White	Black	Speckled

Figure 2.40 White feathers and black feathers are codominant traits. The evidence of this is the heterozygote offspring of the white and black chickens above, which has a mix of black and white feathers.

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VIDEO
Blood types

Blood types

In humans, blood type is a codominant trait. Our red blood cells have proteins on the surface called antigens, and these determine whether our blood is A, B, AB or O. The I gene is often used in genetic notation for the ABO system. The I stands for the isoagglutinogen gene, which determines the presence of blood group antigens.

Each person has two copies of the isoagglutinogen gene, one from their mother and one from their father. This gene is found on chromosome 9, and there are three possible alleles:

- I^A = production of antigen A (type A blood) is dominant.
- I^B = production of antigen B (type B blood) is dominant.
- i = production of neither antigen (type O blood) is recessive.

As we have two copies of chromosome 9, there can be six different allele combinations:

- Type A blood can have the genotypes I^AI^A or I^Ai.
- Type B blood can have the genotypes I^BI^B or I^Bi.
- Type AB blood can only have the genotype I^AI^B.
- Type O blood can only have the genotype ii.

Blood types A and B are dominant over type O, but they are codominant to each other.

Worked example 2.7

Cross between heterozygous blood type A and heterozygous blood type B

Parents: $I^Ai \times I^Bi$

Gametes	I^A	i
I^B	I^AI^B	I^Bi
i	I^Ai	ii

F_1 genotype: 25% $I^A I^B$; 25% I^B i; 25% I^A i; 25% ii

F_1 phenotype: 25% AB blood type; 25% B blood type; 25% A blood type; 25% O blood type

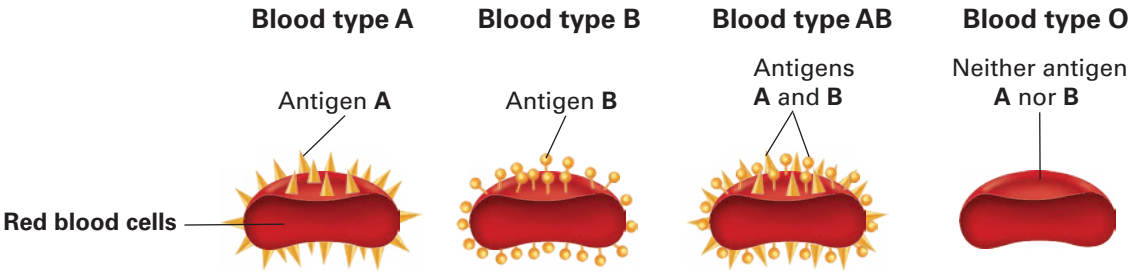

Figure 2.41 Illustration of the different antigens on the surface of red blood cells

Explore! 2.5

incomplete dominance a form of inheritance in which both alleles are partially expressed, producing a third intermediate phenotype

Incomplete dominance

Incomplete dominance occurs when neither of two traits is dominant over the other when expressed in a heterozygote, resulting in a third phenotype which is an intermediate form of both. Wavy hair is an example of incomplete dominance. A person with two curly hair alleles (CC) will have curly hair. A person with two straight hair alleles (SS) will have straight hair. However, a person with one curly and one straight allele (CS) will have wavy hair. To distinguish

continued …

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between different versions of the same gene, alleles are often written with the same letter but in superscript. For example, H^CH^C could represent two curly hair alleles, and H^SH^S could represent two straight hair alleles. In this way, H^CH^S would indicate the heterozygous condition, resulting in wavy hair as an intermediate phenotype.

1. The flower colour of snapdragons is an example of incomplete dominance. Draw an example of a cross for a white flower (C^WC^W) and a red flower (C^RC^R).
2. Eggplant colour is another example of incomplete dominance. Explain how the three colours of eggplant shown in Figure 2.43 are possible.

Figure 2.42 Wavy hair is an example of incomplete dominance.

Figure 2.43 Deep purple (left), violet (middle) and light green (right) eggplants

Quick check 2.14

1. **Explain** why males are more likely to be affected by recessive X-linked disorders than females.
2. **Describe** codominance.

Pedigrees

One way of finding out how a trait is inherited is to follow the inheritance pattern over two or more generations. This technique is called pedigree analysis. To study patterns of inheritance in humans, geneticists investigate the frequency and occurrence of a particular gene over many generations to determine whether the traits are dominant or recessive. The chart formed is called a **pedigree**, and it is like a family tree.

WORKSHEET Pedigrees

pedigree a chart that shows relationships between family members and indicates which individuals have certain genetic traits

Each generation is numbered in Roman numerals and forms a row on the pedigree. Individuals are numbered using Arabic numerals (1, 2, 3, etc.) from left to right on each row. The symbols used are:

- Unaffected female
- Unaffected male
- Female with the trait being investigated
- Male with the trait being investigated
- Carrier of trait or
- Mating is represented by a horizontal line
- A vertical line connects offspring to parents

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Reading a pedigree

There are some points to keep in mind when reading a pedigree and determining inheritance:

- A trait that is common in a population is not necessarily dominant.
- When asked to determine a genotype in a pedigree, you will need to establish the mode of inheritance. You can use Punnett squares to help you.

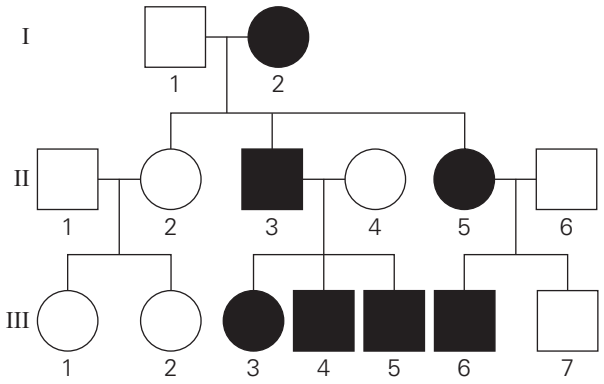


Figure 2.44 An example of a pedigree showing three generations of a family. Individuals affected by a particular trait are shown in black. Note how male I-1 and female I-2 had three children, and their eldest is an unaffected female (II-2).

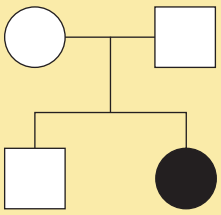
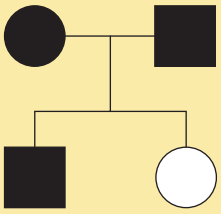
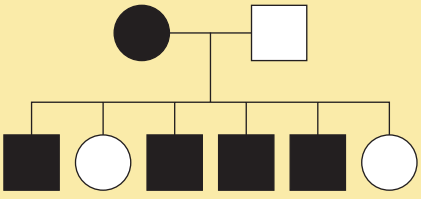
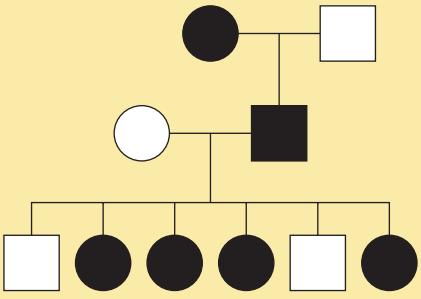
Mode of inheritance	Pedigree chart	What to look for	Examples
Autosomal recessive		Two unaffected parents can have an affected child. Males and females are equally affected. The trait may disappear from a branch of the pedigree and then reappear in later generations. Two affected parents produce children that are all affected.	Albinism, cystic fibrosis, sickle cell anaemia and thalassaemia
Autosomal dominant		Two affected parents can have an unaffected child. Males and females can be equally affected, yet all of the affected individuals must have at least one parent affected.	Huntington's disease and haemochromatosis (types 4 and 5)
X-linked recessive		Affected mothers produce affected sons. Affected fathers *cannot* pass the trait to their sons.	Colour blindness, haemophilia and Duchenne muscular dystrophy
X-linked dominant		Affected fathers produce daughters that are all affected. Affected fathers *cannot* pass the trait to their sons, but affected homozygous females will pass the trait on to all of their daughters and sons.	X-linked hypophosphatemic rickets

Table 2.5 Different modes of inheritance and how to identify them in a pedigree chart

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Did you know? 2.8

Famous people have genetic disorders too!

Megan Fox has a condition called brachydactyly. This is an autosomal dominant condition that causes shortened fingers or toes. Jessie J has Wolff–Parkinson–White syndrome, an autosomal dominant condition that causes a very fast heart rate.

Figure 2.45 Megan Fox and Jessie J both have genetic disorders.

Quick check 2.15

1. Study the pedigree chart in Figure 2.46. It illustrates the inheritance of Wilson's disease in humans.

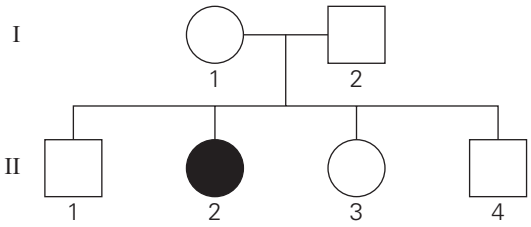

Figure 2.46 Pedigree chart

a) **Identify** a piece of evidence that suggests that this condition is recessive and not dominant.
b) **Identify** the genotype of individuals I-1, I-2, II-1 and II-2.
c) Suppose individual II-2 has children with a man who does not have Wilson's disease but is a carrier for the condition. **Determine** the chance of having a child with Wilson's disease and the chance of having a child without Wilson's disease. Use a Punnett square to show how you arrived at your answer.

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Section questions

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Section 2.3 questions

Remembering

1. **State** how many copies of each gene we have and where they come from.
2. **Recall** the name of the person known for being the father of genetics.
3. **Name** an example of codominance and of incomplete dominance.

Understanding

4. **Describe** what pedigrees are useful for.
5. **Explain** how sex linkage is different from other types of inheritance.
6. **Explain** why, for a particular characteristic, two homozygous recessive individuals can only produce homozygous recessive children.
7. **Explain** what is meant by the term 'carrier'.
8. **Explain** why a test cross is useful.

Applying

9. Dimples are dominant to no dimples.
   a) **Select** appropriate letters for these alleles.
   b) **Identify** the genotype and phenotype of a person who is:
      i) homozygous recessive for dimples
      ii) heterozygous for dimples
      iii) homozygous dominant for dimples.

Analysing

10. The pedigree chart in Figure 2.47 shows the inheritance pattern of a disease that is caused by a single gene.
    a) **Identify** the sex of the person labelled II-5.
    b) **State** whether the disease is dominant or recessive, giving reasons for your answer.
    c) **State** the genotype of individual II-5, giving reasons for your response.

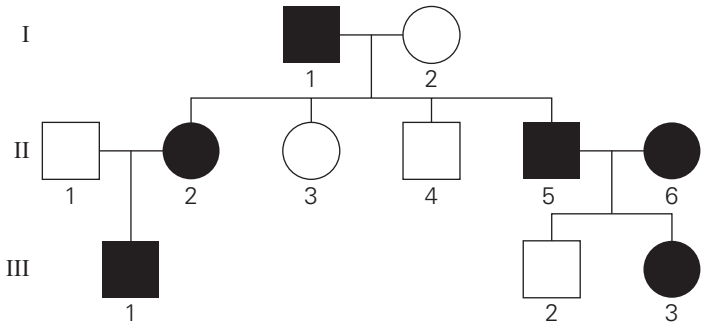

Figure 2.47 Pedigree chart

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11. **Contrast** codominance and incomplete dominance.
12. The pedigree chart in Figure 2.48 shows the inheritance patterns for haemophilia. Haemophilia is an X-linked recessive disorder.
    Use evidence from the pedigree to **justify** that haemophilia is recessive.

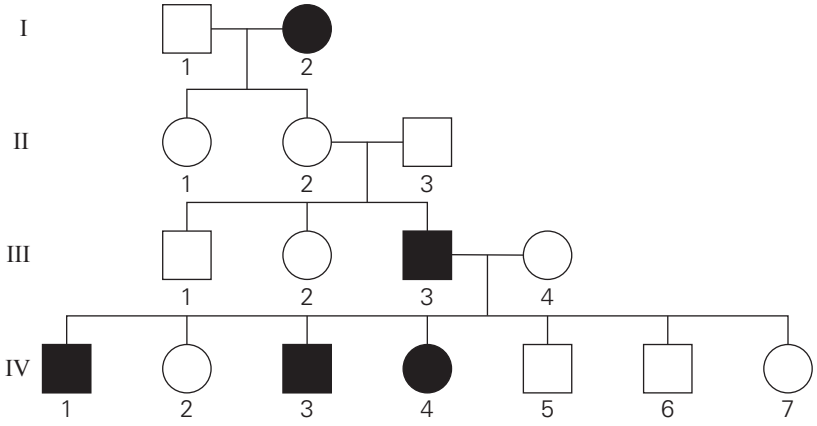
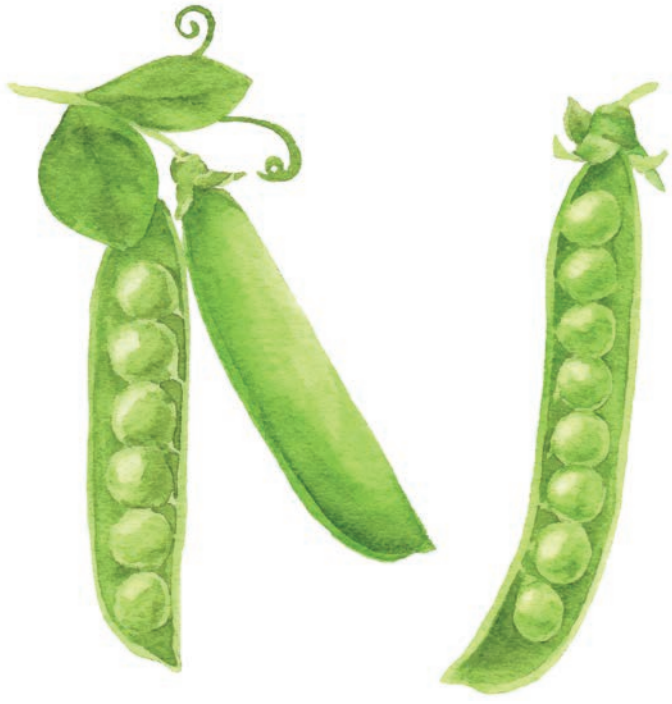


Figure 2.48 A haemophilia pedigree

Evaluating

13. In fruit flies, eye colour is sex linked. The eye colour allele is located on the X chromosome. Red eyes are dominant whereas white eyes are recessive.
    a) **Select** appropriate letters for the alleles of these traits.
    b) Using a Punnett square, **determine** the offspring a male heterozygous fly that mates with a female homozygous recessive fly will produce.
    c) **Decide** the genotypic and phenotypic ratios of the offspring.
14. In mice, black hair is dominant to brown hair. Mice with black hair can be either homozygous or heterozygous.
    Propose how you would find out if a mouse with black hair was homozygous or heterozygous. Support your response with a Punnett square.
15. A brown-eyed male and a blue-eyed female produced all blue-eyed children. **Discuss** whether that means blue eyes is the dominant trait.



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2.4 Changes in DNA

Learning goals

At the end of this section, I will be able to:

1. Distinguish germline and somatic mutations.
2. Recall types of point and chromosome mutations.
3. Explore the applications of DNA manipulation.

WORKSHEET Changes in DNA

Sometimes, the process of DNA replication makes errors, which cause changes to the genetic code. Often these errors are repaired, but when they are not, they become permanent changes in the genome of the cell. This is known as a mutation. Mutations may be small, such as a change in a single nucleotide (**point mutation**), or large, involving entire segments of DNA within a chromosome (**chromosome mutation**). Mutation is the only way that new alleles can be created within a population.

A mutation can be described as **spontaneous** (naturally occurring) or **induced**. Induced mutations are caused by exposure to **mutagenic** agents in the environment like radiation (X-rays, ultraviolet rays or nuclear radiation) or chemicals. Mutations that occur within the gametes are called **germline mutations**. These can be inherited and will influence the next generation. Mutations that occur within somatic cells will only affect the individual and will not be passed down to future generations. This form of mutation is known as a **somatic mutation**.

point mutation a mutation in which a single nucleotide is changed

chromosome mutation a mutation involving large segments of DNA

spontaneous mutation a naturally occurring mutation

induced mutation a mutation produced by environmental factors

mutagenic causing mutations in DNA

germline mutation a mutation of DNA in gametes, which can be inherited

somatic mutation a mutation that occurs in somatic (body) cells and that cannot be inherited

Explore! 2.6

Mutagens

Many factors in the environment are known as 'mutagens' – that is, they cause mutations.

1. Research some environmental mutagens.
2. From the list created in Question 1, divide your mutagens into categories according to their source, such as chemical mutagens and radiation.

Figure 2.49 Melanoma is linked to UV light exposure as well as gene changes. A mole may be a sign of skin cancer if it has irregular borders, an asymmetrical shape or if it changes in colour, shape, size or height.

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Did you know? 2.9

The Black Death left a genetic mark

Many individuals with European ancestry carry genetic mutations that protected their ancestors from the bubonic plague, a disease caused by *Yersinia pestis*, a species of bacterium spread by fleas. When plague struck Europe in 1348 and again in 1665, millions of people died. However, some people had mutations that made them more likely to survive.

By examining the DNA of people who died before, during and after the Black Death, researchers have found that carrying two copies of a mutated ERAP2 gene improved a person's survival by 40%. The allele codes for a protein that is involved in the immune response, and the mutation produced a heightened response. This meant that the survivors of bubonic plague passed on this beneficial trait to their offspring. However, this mutation is also problematic. Individuals who carry the mutated ERAP2 gene are at an increased risk of autoimmune diseases.

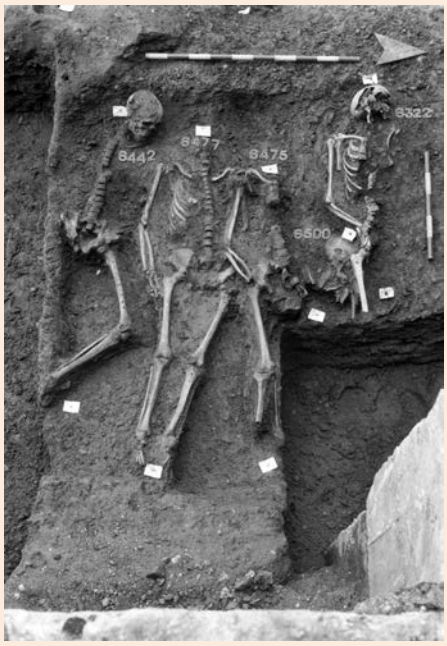

Figure 2.50 A mass burial pit of plague victims excavated in East Smithfield, London. The significant number of deaths during plague outbreaks resulted in many similar mass burials across Europe.

Beneficial, harmful, and neutral mutations

Mutations have three possible consequences:

- **No effect – neutral**. Neutral mutations are non-lethal and make no difference to the organism's ability to survive and reproduce in its environment.
- **Negative effect – harmful**. Harmful mutations produce proteins that malfunction or cause proteins not to be produced at all. They can cause genetic disorders or cancer and result in organisms that are less likely to survive, reducing the likelihood that the genetic material will be passed on to the next generation.
- **Positive effect – beneficial**. Beneficial or advantageous mutations give rise to new versions of proteins that increase the chance that the organism will survive and reproduce to pass its genetic material to the next generation. Beneficial mutations increase genetic variation in a population and are essential for evolution to occur.

Quick check 2.16

1. If a mutation is to be passed on to the next generation, **recall** where it must occur.
2. **Summarise** the possible effects of mutations that occur in somatic cells.

Gene mutations

Gene mutations refer to changes in the DNA sequence that makes up a gene. This involves changes to any of the four nitrogenous bases in the nucleotides that make up the genes.

gene mutation a permanent alteration in the DNA sequence that makes up a gene

There are several types of gene mutations, including point mutations, insertions, deletions and inversions.

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substitution where one nucleotide is swapped for another

insertion where one or more extra nucleotides are inserted into the DNA

deletion where a nucleotide is deleted from the DNA sequence

inversion where two nucleotides reverse their order

Changing the nucleotides could change the message carried by the gene, which may change the order of amino acids making up the protein.

- A point mutation is the most common type of gene mutation, and involves the **substitution** of one nucleotide for another (for example, ATG becomes ACG). This mutation only changes the DNA code for a single amino acid. If the new sequence codes for the same amino acid, it is called a silent mutation. An example of a disease caused by a substitution mutation is sickle cell anaemia.
- An **insertion** mutation occurs when an extra nucleotide (or more than one) is inserted into the DNA sequence (for example, ATG becomes ATCG). This type of mutation changes the DNA code for all amino acids that follow and is called a frameshift mutation. An example of a disease caused by an insertion mutation is fragile X syndrome.
- A **deletion** mutation occurs when a nucleotide is deleted from the DNA sequence (for example, ATG becomes AG). This type of mutation changes the DNA code for all amino acids that follow and is also a frameshift mutation. An example of a disease caused by a deletion mutation is Duchenne muscular dystrophy.
- An **inversion** mutation occurs when two nucleotides reverse their order in the DNA (for example, ATG becomes AGT). This mutation only changes the DNA code for a single amino acid, and it could code for the same amino acid (silent mutation). An example of a disease caused by an inversion mutation is haemophilia.

Try this 2.7

Remembering mutations

Find a way to remember the different types of mutations using normal words.

For example:

- normal code – WING
- deletion – WIG
- substitution – WIND
- insertion – WRING.

Chromosomal changes

Chromosome mutations

If a mutation occurs in a gene on one of the pair of homologous chromosomes, there will still be a normal copy of the gene on the other chromosome. The same applies with chromosome mutations. As chromosomes occur as homologous pairs, if one chromosome is abnormal, the other is still likely to be normal. The different types of chromosome mutations are illustrated in Figure 2.51.

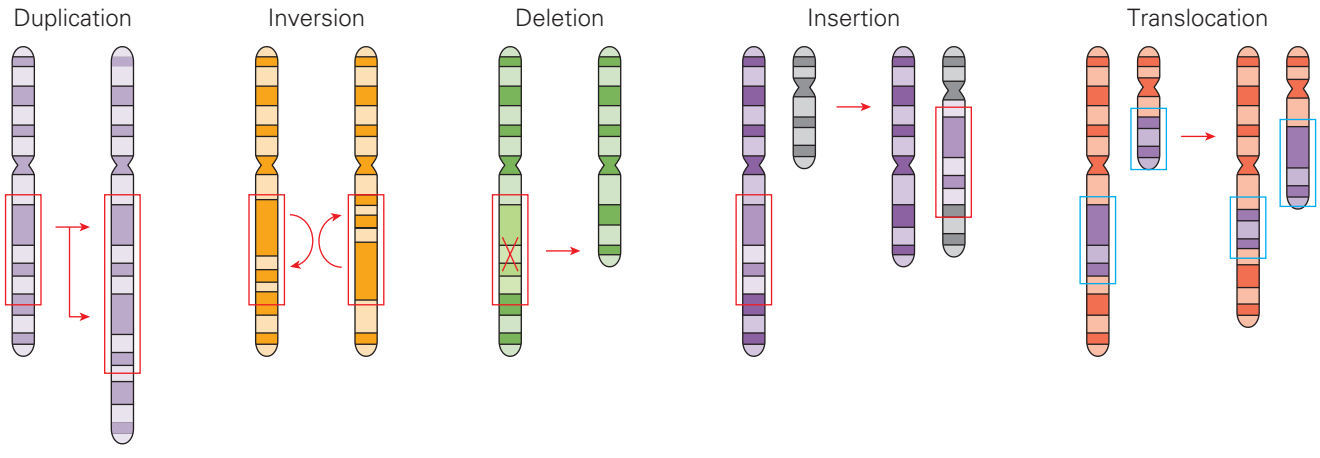

Figure 2.51 The five different types of chromosome mutation. Can you identify what is changing in each type?

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Chromosome number abnormalities

Certain individuals may have one more or one fewer chromosome because of **non-disjunction** during meiosis. Non-disjunction means that the chromosomes failed to separate correctly when making gametes, so the gametes end up with an abnormal number of chromosomes (**aneuploidy**).

Trisomy occurs when an organism has a third copy of a chromosome that should only be present in two copies. Trisomy is therefore an example of aneuploidy. The most common trisomy among embryos that survive to birth is Down syndrome, or trisomy 21. People with this inherited disorder have distinct facial characteristics and experience developmental delays.

non-disjunction the failure of homologous chromosomes or sister chromatids to separate correctly in meiosis

aneuploidy the presence of an abnormal number of chromosomes in a cell

trisomy when an organism has a third copy of a chromosome

Did you know? 2.10

Sex chromosome abnormalities

Sex chromosome abnormalities occur when a person is missing a whole sex chromosome or has an extra sex chromosome due to non-disjunction. Problems can also occur when a person is missing part of a sex chromosome. Some disorders of sex chromosome are Klinefelter syndrome, XX male, XYY male, Turner syndrome, XXX female and XY female. Some of these disorders are surprisingly common. For example, many men with Klinefelter syndrome (who have two X chromosomes and one Y) have no signs or symptoms, and it is estimated that only one in six are ever diagnosed.

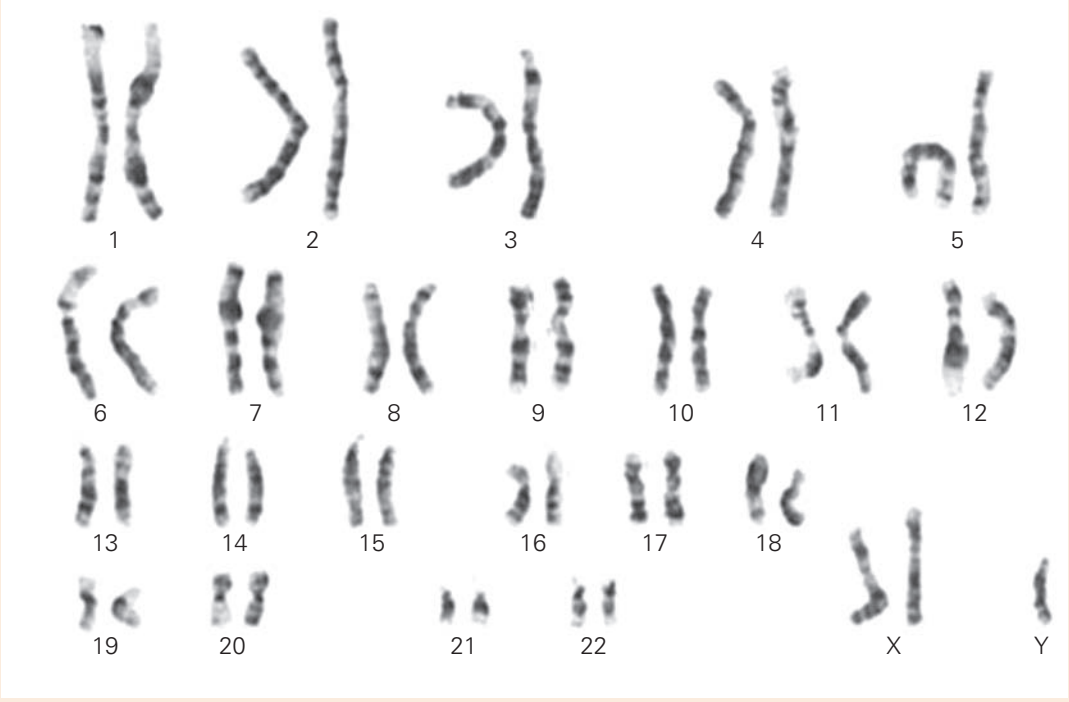

Figure 2.52 A karyotype of a male with Klinefelter syndrome

Quick check 2.17

1. **Describe** a substitution mutation.
2. **Recall** what the term 'aneuploidy' means.

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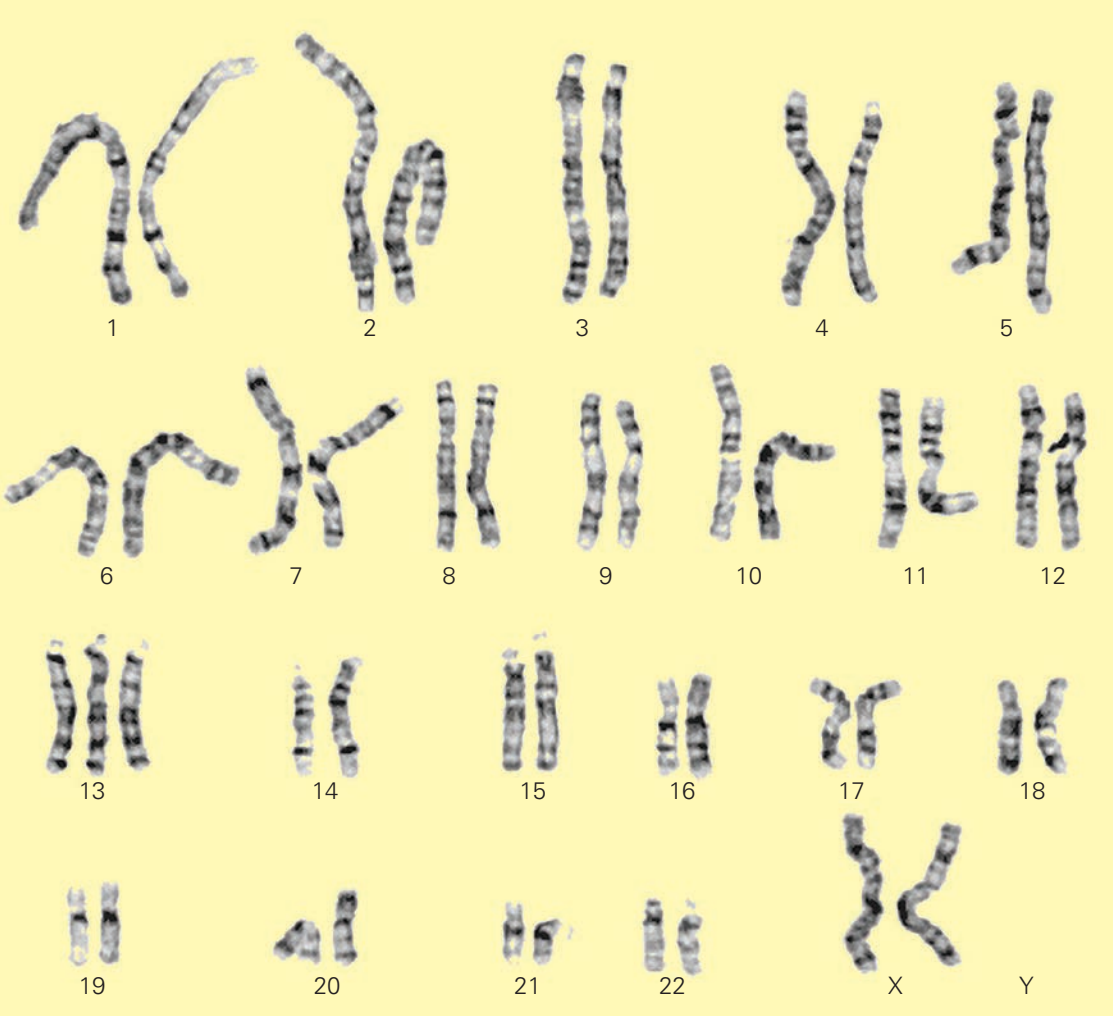

Figure 2.53 There are other types of trisomy apart from trisomy 21. Trisomy 13 and 18 result in more severe conditions. Which trisomy is depicted in this karyotype?

Did you know? 2.11

Madeline Stuart

Madeline Stuart is the first professional model with Down syndrome, and she is Australian! Although the fashion industry has a long way to go in terms of diversity, Madeline is one of the women who are changing the game. As well as being a model, she has also represented Queensland at the Special Olympics in cricket and basketball.

Figure 2.54 Madeline Stuart models at the New York Fashion Week.

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DNA testing

A person's DNA can provide information relating to their ancestry or parentage, confirm if they have a hereditary disease, and inform whether they are a carrier for genetic disorders that may affect their children.

genetic screening genetic tests carried out across the population to identify people at risk of genetic disorders

Genetic screening is a type of genetic testing, but instead of identifying a genetic condition, it is used to evaluate an individual's risk of developing a certain disease. These tests are routinely done for anyone in the population, even if they have not shown a family history of the disease. Genetic screening is usually done during pregnancy and at birth. In Australia, about 99% of babies are screened every year. Of the babies screened, around one in every thousand has a condition that would otherwise have gone undetected. Genetic screening provides an opportunity for preventive measures and early treatment.

Figure 2.55 In Western Australia, the newborn bloodspot screening test screens for conditions such as cystic fibrosis, phenylketonuria, hypothyroidism, galactosaemia and congenital adrenal hyperplasia.

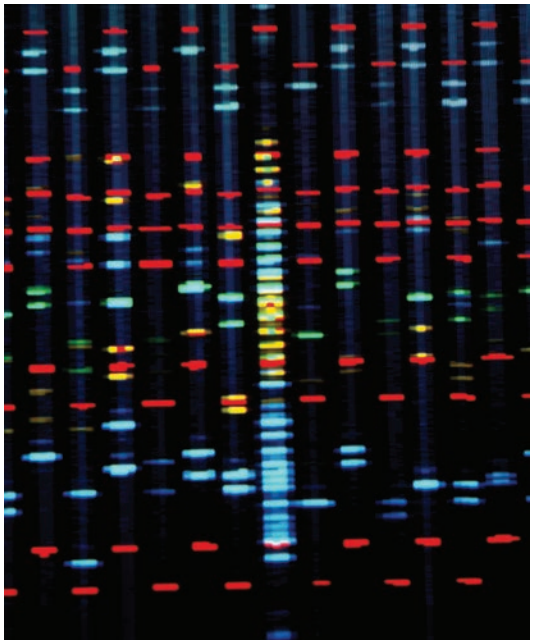


Figure 2.56 A DNA sequence or 'genetic fingerprint' on a computer monitor. The development of fast computers made the analysis of DNA sequences possible.

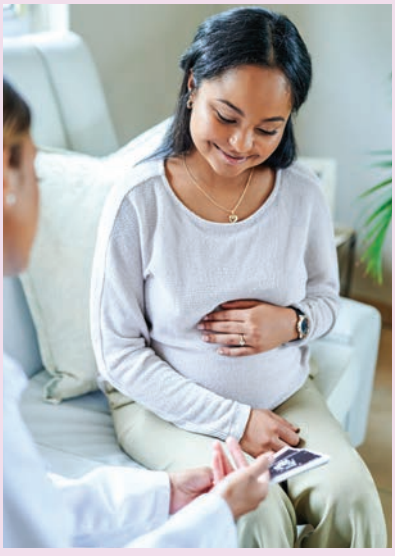
Making thinking visible 2.2

Think, feel, care: Genetic screening

In your class, divide into teams and engage in a discussion about perspectives within a scenario about genetic testing. You may wish to consider the following scenario, although your teacher may provide you with an alternative.

A woman who is 12 weeks pregnant attends a clinic and expresses her concern about her husband's family history of Huntington's disease (HD). Her sister-in-law tested positive last year, although she is not yet showing symptoms of the disease, but the woman's husband refuses to be tested. Due to this, the woman is asking for her unborn baby to be screened to determine whether it carries the HD gene. If the test comes back positive, which means that her husband carries the HD gene, the woman will discuss terminating the pregnancy with her husband.

Step inside each person's point of view in this scenario. As you think about what you know, consider what each person might understand, respond to and value in the issues raised. Don't forget to consider the legal and ethical issues.



The *Think, feel, care* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Science inquiry 2.2

Precision medicine

Pharmacogenomic tests look for genetic variants that are associated with an individual's response to specific medicines, by testing genes that affect drug metabolism. Its goal is to help doctors to select the drugs and doses that are best suited to each person.

Figure 2.57 Research has shown that people with red hair tolerate pain differently to people with other hair colours. Due to a mutation on the MC1R gene, they require more anaesthesia but need lower doses of opioids as they are more responsive to those painkillers.

Quick check 2.18

1. **Explain** why an individual might choose to be screened for genetic diseases.
2. **Identify** some ethical issues with genetic testing.

VIDEO
CRISPR

Manipulating DNA

Genetic engineering technology allows scientists to manipulate genetic material and transfer genes between different organisms. One of the most exciting developments of the last decade is CRISPR, a technology that can edit genetic material quickly and cheaply. Developed by Jennifer Doudna and Emmanuelle Charpentier, the CRISPR tool lets scientists change or delete DNA bases and insert entirely new genes (see Figure 2.58). The gene editing technology has almost endless potential, including editing crops so they're more nutritious or able to survive in different conditions, curing genetic diseases, producing powerful new drugs or even resurrecting extinct species. In 2022, a New Zealand woman became the first to receive CRISPR treatment to treat heart disease by permanently lowering her cholesterol.

genetic engineering deliberately modifying genetic material to manipulate the characteristics of an organism

genetically modified organism an organism that has had its genome altered using genetic engineering techniques

Genetically modified organisms

A **genetically modified organism** (GMO) is an organism whose genome has been altered by humans. Commonly, they are crop species that have been modified to improve growth rates, yield, quality and nutritional value. Genetic modification can decrease pest and disease susceptibility, reducing the need for pesticides.

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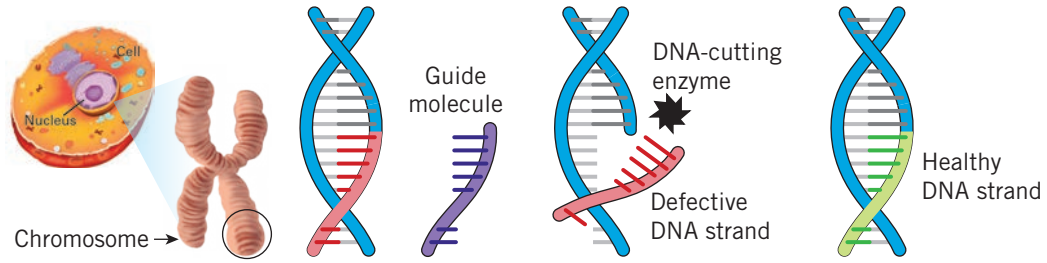
Cell
Nucleus
Chromosome
Guide molecule
DNA-cutting enzyme
Defective DNA strand
Healthy DNA strand
A cell is transfected with an enzyme complex containing a guide molecule, a DNA-cutting enzyme and a copy of healthy DNA.
The guide molecule finds the target DNA strand.
The enzyme cuts out the target DNA strand.
The healthy DNA copy replaces the defective DNA.

Figure 2.58 CRISPR gene editing technology allows DNA to be manipulated in a highly precise way.

Agricultural practices have changed to include the widespread use of genetically engineered crops. Crop plants are modified to have a greater tolerance to environmental stressors such as drought or heavy metals, allowing plants to grow in new areas. For example, some plants have been genetically engineered to grow with less water so that they are more resistant to climate change. Until recently, only three GM crops were approved to be grown in every mainland Australian state: canola (rapeseed oil), cotton and safflower. After a ban was lifted, a wider range of GM crops can now be grown in every mainland state.

Try this 2.8

GM food

A great debate continues to rage within society regarding the health risks associated with eating GM food. Research two advantages and two disadvantages of the use of GM food and be prepared to debate with your classmates.

Figure 2.59 Cassava root has been genetically modified to have increased levels of beta carotene (right). This decreases post-harvest deterioration and also improves the nutritional value of the crop.

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Did you know? 2.12

De-extinction

'De-extincting' is the process of bringing an extinct species back to life through genetic engineering by using fragments of DNA from preserved specimens. De-extincting species is a controversial idea, and many scientists argue that funding would be better spent conserving existing species and their habitats.

A start-up biotechnology company called Colossal Biosciences quickly raised millions of dollars after announcing plans to de-extinct the woolly mammoth, the thylacine and the dodo. In 2025, the company claimed to have revived the dire wolf, last seen over 10 000 years ago. A white wolf featured on the cover of *Time* magazine, named as one of three 'dire wolf' puppies – Romulus, Remus and Khaleesi.

Figure 2.60 Colossus Biosciences has produced three genetically engineered dire wolf puppies by using modern grey wolves and ancient DNA retrieved from the remains of extinct dire wolf ancestors. The DNA was inserted using CRISPR technology.

However, scientists soon clarified that these were genetically edited grey wolves. With dire wolf DNA too fragmented to clone, researchers had inserted selected gene sequences into grey wolf embryos to mimic some traits.

Figure 2.61 Golden rice and normal rice

Figure 2.62 Mosquitoes have been genetically modified to slow the growth of malaria-causing parasites in their gut, preventing transmission of the disease to humans.

Genetic engineering is also helping to alleviate global malnutrition and disease. A type of rice called golden rice has been engineered to prevent blindness in children caused by vitamin A deficiency (see Figure 2.61). Another type of GM rice has been developed that has four times more iron than normal rice.

transgenic organism an organism that possesses a foreign gene or segment of foreign DNA in its genome because of human experimentation

Transgenic organisms (TGOs) are the result of a type of genetic modification where a 'foreign' gene, or a segment of 'foreign' DNA is inserted into an organism's genome. This was done to mosquitoes, for example, to prevent the transmission of malaria to humans (see Figure 2.62). A foreign gene is one that is taken from another species. All transgenic organisms are GMOs, but not all GMOs are transgenic.

By inserting human genes into mice, human diseases can be mimicked, particularly as the genome and physiology of mice are so similar to humans. Transgenic mice are being used to study conditions such as obesity, heart disease, diabetes and Alzheimer's disease. Transgenic pigs are being investigated as a source of organs for transplants, which could address severe donor organ shortages. CRISPR technology has greatly reduced the complexity of the creation of transgenic animals, making the process faster and cheaper.

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Explore! 2.7

Genetically modified tomatoes

Many foods come from genetically modified organisms, and we call them GM foods. The Flavr Savr tomato was the first commercially grown GM food that was granted a licence for human consumption. Released in 1994, the tomato had an improved shelf life and was developed for long-distance shipping. Recently, a GM tomato has been developed that contains higher levels of anthocyanins, a pigment that occurs naturally in purple or blue fruits and vegetables such as blueberries or red cabbage. By transferring a snapdragon gene into a tomato's genome, they have produced a purple tomato that has the same levels of anthocyanins as blueberries.

1. Research why the team chose to genetically modify a tomato.
2. The high levels of anthocyanins in the purple tomatoes are beneficial for several reasons. Research the effect of anthocyanins on:
   a) shelf life
   b) plant reproduction and survival
   c) human health.

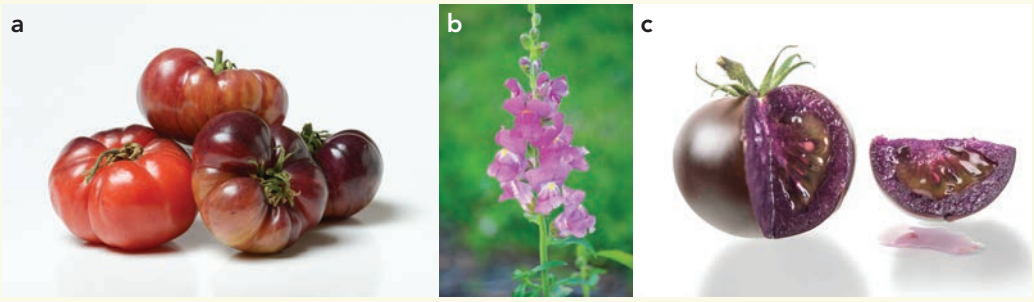

Figure 2.63 The process by which the John Innes Centre and the Sainsbury Laboratory created a GM purple tomato, which was approved for growing and breeding in the US in 2022. **(a)** Existing purple-skinned tomatoes do not contain useful levels of anthocyanins. **(b)** Genes from purple snapdragon flowers were added to the tomato. The snapdragon genes act like 'on switches', causing the purple pigment to be expressed throughout the tomato, instead of just in the skin. **(c)** The resulting purple tomato is high in anthocyanins, which have a range of benefits for human health.

Human genes have been engineered into other mammals to supply the protein products of those genes, usually for medical purposes. For example, transgenic goats have been genetically engineered to produce milk that contains human antithrombin III. This is a protein that is used to prevent clots in patients with hereditary antithrombin deficiency when they are in surgery or giving birth. A herd of approximately 80 goats could supply enough human antithrombin III for all of Europe.

Figure 2.64 Transgenic C5 plums contain a gene that makes them resistant to plum pox virus.

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Figure 2.65 A CSIRO study found that genetically modified sheep grow bigger and faster and can produce more milk and wool. However, they required more care than non-GM sheep.

Making thinking visible 2.3

I used to think ... now I think ... : Xenotransplantation

Xenotransplantation is the transplantation of living cells, tissues or organs from one species to another. Transgenic pigs are promising xenotransplantation donor organisms as they share many anatomical and physiological characteristics with humans. In 2022, the first pig-to-human heart transplant took place. The operation was successful and, due to genetic modification, the heart was not rejected by the patient's immune system. Unfortunately, he died 60 days later; scientists are still investigating why this happened. Scientists have also been successful in transplanting genetically modified pig kidneys into a brain-dead patient, with them functioning normally throughout the study period.

Think about what you have learned about transgenic organisms and xenotransplantation and complete the following sentence stems.

In the past, my viewpoint was …

Currently, my viewpoint is …

The *I used to think ... now I think ...* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Gene therapy

gene therapy a process by which a copy of a functional gene is introduced into an organism

Gene therapy is a process by which a copy of a functional gene is introduced into an organism. The gene is then switched on to produce the functional protein that is missing. This technique aims to treat inherited disorders like cystic fibrosis by directly targeting the genotype (unlike treatments that target the symptoms). Technical difficulties may arise when trying to specifically target the cells of

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affected tissue, and when targeting one specific gene without interfering with the function of other essential genes. Ethical issues also arise. Some people argue that gene therapy should be restricted to somatic tissue only, so the introduced gene is not transmitted through to the next generation. What do you think about this issue?

Science inquiry 2.3

DNA data storage

Digital technology currently works using the binary system, which only uses the digits 0 and 1. Any information that is input digitally is converted to this system, and digital devices will change those values to the necessary form of information. It's predicted that by 2035 the total volume of digital data generated by humans is expected to reach 2142 zettabytes (a zettabyte is equivalent to 1 000 000 000 000 000 000 000 bytes). Currently, most data is stored in the 'cloud', but the cloud is actually huge data centres stored in warehouses that require large amounts of energy to run.

However, by translating binary (0 or 1) values into one of the four DNA bases, it is possible for DNA to be reliably used to store huge amounts of digital data. Some scientists say that the entire world's data could be stored in DNA that would fill a shoebox.

Rather than storing 0s and 1s individually, DNA allows them to be stored in pairs such as this:

- 00 A
- 01 T
- 10 C
- 11 G.

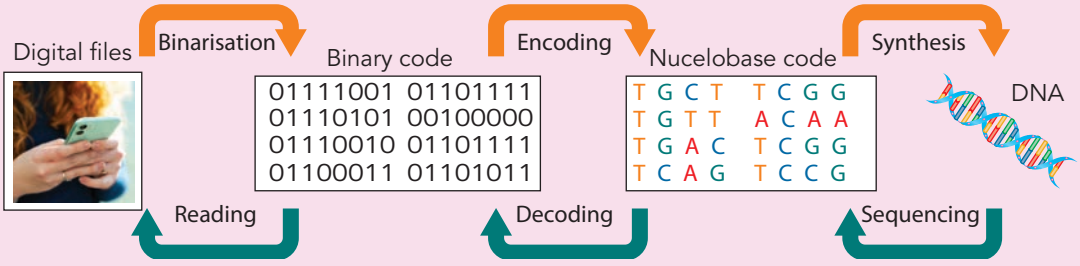

Figure 2.66 Encoding data into DNA code might be the future of efficient data storage.

After storing data in DNA, it can then be read using a DNA sequencer. This reads all of the bases and then converts it to binary. Improvements in sequencing techniques allow for billions of DNA sequences to be easily read at once and, when kept in suitable conditions, DNA can be preserved for hundreds of thousands of years without any energy input.

New sequencing techniques are also allowing sections of DNA to be used as identification tags. This DNA barcoding is accelerating the pace of research in fields such as chemical engineering, materials science and nanotechnology.

Quick check 2.19

1. **Recall** what GMO stands for.
2. **Describe** the process of gene therapy.
3. **State** an example of the application of genetic screening.
4. **Discuss** the reasons for the adoption of genetic screening by groups in society.
5. **State** five conditions that are screened for in Western Australia through the newborn bloodspot screening tests.

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Section 2.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.4 questions

Remembering

1. If a mutation is to be passed on to the next generation, **state** where it must have occurred.
2. **Define** the term 'mutagen'.
3. **Recall** the definition of a genetically modified organism.

Understanding

4. Using the table below, answer the following questions.

Second letter in the codon

First letter in the codon	U		C		A		G		Third letter in the codon
U	UUU	Phe (F)	UCU	Ser (S)	UAU	Tyr (Y)	UGU	Cys (C)	U
	UUC		UCC		UAC		UGC		C
	UUA	Leu (L)	UCA		UAA	STOP	UGA	STOP	A
	UUG		UCG		UAG	STOP	UGG	Trp (W)	G
C	CUU	Leu (L)	CCU	Pro (P)	CAU	His (H)	CGU	Arg (R)	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	Gln (Q)	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	IIe (I)	ACU	Thr (T)	AAU	Asn (N)	AGU	Ser (S)	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	Lys (K)	AGA	Arg (R)	A
	AUG	Met (M) START	ACG		AAG		AGG		G
G	GUU	Val (V)	GCU	Ala (A)	GAU	Asp (D)	GGU	Gly (G)	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	Glu (E)	GGA		A
	GUG		GCG		GAG		GGG		G

The original DNA strand is GTC GGG ATA CGG CTC.
A gene mutation occurs, whereby the C in the first codon is replaced with a T, resulting in GTT GGG ATA CGG CTC.

a) **State** the name of this gene mutation.
b) **State** the mRNA strand that was copied from the original DNA strand.
c) **State** the new mRNA strand produced from the mutated DNA strand.
d) **State** whether the amino acids stay the same or change.
e) Another mutation occurs, whereby a C was added to the beginning of the above original DNA strand, giving CGTC GGG ATT CGG CTC.
State the name of this mutation and describe how it would affect the subsequent amino acids that the gene codes for.
f) Write out the mRNA code for this mutation and **identify** the corresponding amino acids.

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Applying

5. **Explain** what will happen if a nucleotide is deleted from the sequence of nucleotides within a gene.
6. **Explain** what usually results when mutations occur in non-germ (somatic) cells.
7. **Explain** whether or not all mutations are detrimental (harmful).
8. **Explain** how a mutated gene can lead to a genetic disorder.
9. **Illustrate** a diagram to outline how non-disjunction may occur and cause aneuploidy.

Analysing

10. **Contrast** a genetically modified organism and a transgenic organism.
11. **Contrast** a spontaneous mutation and an induced mutation.

Evaluating

12. Using the DNA sequence ACAATTGGTAGCTGAGTTGGCCCGTA, **create** an example of the following mutations:
    a) substitution
    b) inversion
    c) deletion
    d) insertion.
13. **Discuss** why the substitution of one nucleotide may not be as critical to the functioning of the protein as the deletion or insertion of a nucleotide.
14. **Propose** an explanation for the relationship between increased rates of skin cancer and the thinning of the ozone layer.
15. **Construct** a mind map that shows the different types of mutations that may occur.

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Chapter review

Chapter checklist

Success criteria		Linked questions
2.1	I can recall the components that make up the structure of DNA and RNA molecules.	6, 13
2.1	I can describe the relationship between genes, DNA and chromosomes.	1
2.1	I can describe the steps in which DNA is used to synthesise proteins.	7, 18
2.2	I can recall the steps involved in DNA replication.	3, 4, 15
2.2	I can describe the stages of cell division in mitosis.	17
2.2	I can describe the stages of cell division in meiosis.	17
2.2	I can use a karyotype to determine information about an individual.	10
2.3	I can define the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive' with respect to genetic inheritance.	5
2.3	I can use and interpret a Punnett square to identify possible genotypes and phenotypes of offspring.	20, 23
2.3	I can explain sex linkage.	11, 19
2.3	I can distinguish between codominance and incomplete dominance.	22
2.3	I can use a pedigree diagram to determine the type of inheritance that is occurring.	19
2.4	I can explain the different types of mutations, including their causes and effects.	16
2.4	I can describe some ways in which DNA can be manipulated.	25

Go online to access the interactive chapter review

Scorcher competition

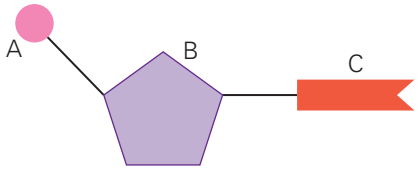
Review questions

Data questions

Review questions

Remembering

1. **State** the name of the position on a chromosome where a particular gene is located.
2. **Recall** two autosomal recessive inheritable traits.
3. **Recall** the name of the enzyme that unwinds the DNA double helix during DNA replication.
4. **Name** the structure formed when DNA condenses and becomes visible before cell division.
5. **Define** the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive'.
6. **Identify** the parts A–C of the nucleotide in the following figure.
7. **State** the location in the cell where transcription and translation occur.
8. **State** how many chromosomes you would expect to find in:
   a) a human somatic cell
   b) a human gamete
   c) a somatic cell of a human with Down syndrome.



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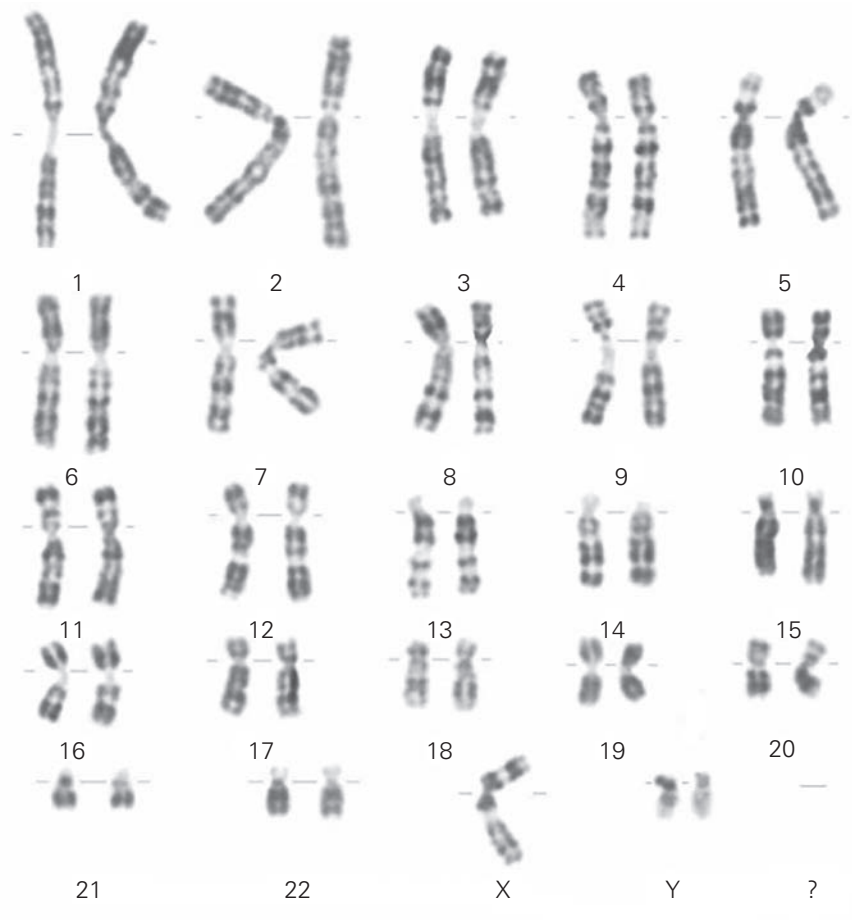
Understanding

9. **Explain** why males have more chance than females of inheriting an X-linked recessive trait.
10. Assuming eye colour in humans is controlled by a single pair of genes, and that brown eyes are dominant to blue eyes, **determine** the genotype of a brown-eyed man if he and a woman with blue eyes produce a baby with blue eyes.
11. **Illustrate** a diagram to show how two nucleotides join together with hydrogen bonds.
12. **Explain** why chromosomes are not always visible.
13. When cells reproduce themselves, the DNA is replicated. **Explain** why this is necessary.
14. **Explain** how aneuploidy occurs.
15. **Contrast** meiosis and mitosis.
16. **Illustrate** a diagram to show the processes of transcription and translation.

Applying

17. **Identify** what information can be gained from the following karyotype.



18. Using a Punnett square, **determine** the genotypes and phenotypes of the children if a normal-vision female carrier of colour blindness has children with a normal-vision male.

Parents: $X^BX^b \times X^BX$

Gametes	X^B	X^b
X^B	X^BY^B	X^BY^b
Y	X^BY	X^bY

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19. **Construct** a pedigree with the following information.

A woman with Huntington's disease marries a man who does not have Huntington's disease. They have three children. The first child is a male, the second child is a female, and both do not have the disease. The third child, a male, does develop the disease. Remember that Huntington's disease is an autosomal dominant genetic disorder.

Analysing

20. The table below shows several different organisms with their diploid chromosome number.

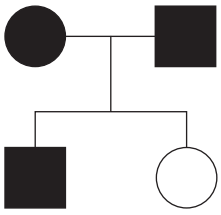
Organism	Chromosome number (2*n*)
Chimpanzee	48
Human	46
Horse	64
Onion	16
House fly	12
Worm	20

a) **Identify** the organism with the highest number of chromosomes in its gametes.

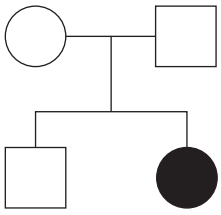
b) **State** the haploid number of the onion.

21. Use information from the following pedigrees to **infer** the inheritance pattern shown.

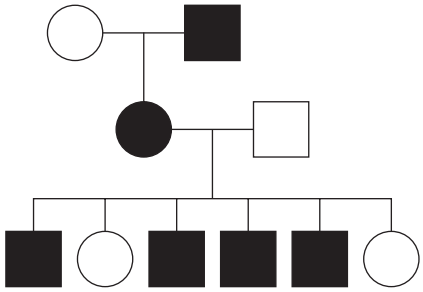
a)



b)



c)



22. An abandoned baby was handed in at the police station. Later, two women claimed to be the baby's mother. Blood studies revealed that woman 1 had blood type A, and that woman 2 had blood type AB. The baby had blood type O. **Deduce** which woman could possibly be the baby's mother and which woman can be ruled out completely. Show your working.

23. Chondrodystrophy is an autosomal recessive condition that is governed by a single gene with two alleles. In turkeys, affected embryos die approximately 16 days after fertilisation, so they do not survive long enough to hatch. Two turkeys that are heterozygous for the condition are crossed. Show your working to **determine** the phenotypic and genotypic ratios of the offspring.

Let T = normal allele and t = allele with chondrodystrophy.

Evaluating

24. Personal genome screening can be readily ordered over the internet. **Evaluate** the pros and cons of having DNA testing so readily available at an affordable cost.

25. You had genome screening and found out that your genes conferred a 25% chance of developing a disease. However, you also know that environmental and lifestyle factors play a large role in whether you develop the disease.

a) **Evaluate** how this information would affect your life.

b) **Discuss** how this scenario is different from knowing about a disease that is not influenced by lifestyle factors.

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Data questions

A student prepared an onion root tip slide and examined the cells using a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

Stage of cell cycle	Number of cells recorded
Interphase	340
Prophase	13
Metaphase	4
Anaphase	3
Telophase	6

Table 2.6 Number of onion cells in each stage of the cell cycle

She then calculated the mitotic index for different areas of the root tip. The graph shows her results.

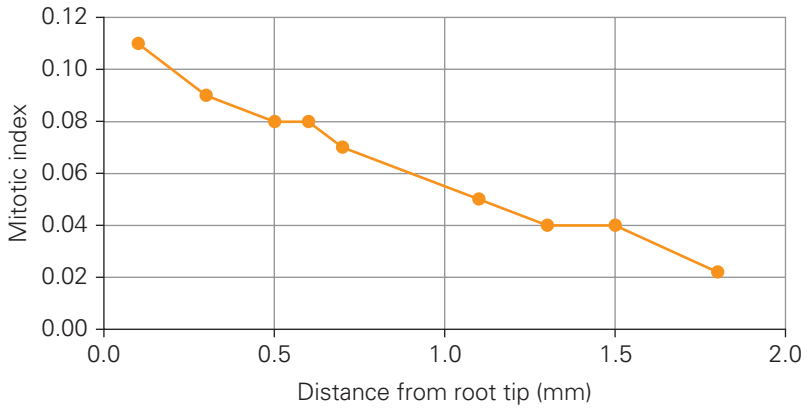

Figure 2.67 Mitotic index plotted against distance from root tip

1. The mitotic index of dividing tissue is calculated with the following formula:

$$\text{Mitotic index} = \frac{\text{number of cells seen that were undergoing mitosis}}{\text{total number of cells seen}}$$

Calculate the mitotic index of the tissue shown in the table.

2. The duration of any phase of the cell cycle can be calculated with the following formula:

$$\text{Phase duration (minutes)} = \frac{\text{number of cells seen in that phase}}{\text{total number of cells seen}} \times \text{cell cycle duration of the organism}$$

The cell cycle duration for the onion is 24 hours.

Calculate the duration of metaphase.

3. **Identify** the trend shown in the graph.
4. **Extrapolate** the data in the graph to estimate the mitotic index of the cells found 2 mm from the root tip.

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STEM activity: Designing and prototyping an assistive device for individuals with a genetic disease

Background information

When a mutation occurs that is not beneficial, complications occur. An example of a disease with genetic causes is scoliosis. Scoliosis is a sideways curvature of the spine that usually occurs before puberty. Genetic diseases such as cerebral palsy and muscular dystrophy can cause scoliosis, but the cause of most cases of scoliosis is unknown.

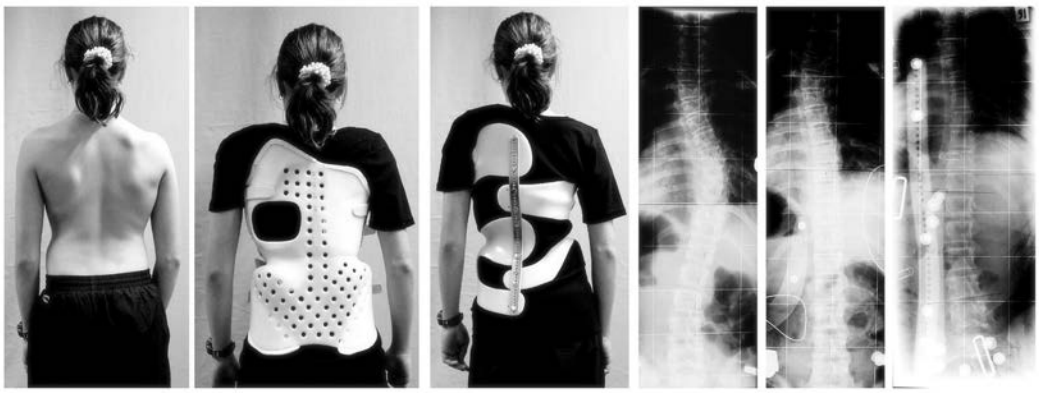

Figure 2.68 Various brace designs can be used for the treatment of scoliosis.

DESIGN BRIEF

Research a genetic disease. Design and build an apparatus that can help to improve the quality of life of people with the selected disease.

Activity instructions

In groups of three or four, conduct basic research on a genetic disease. Then design an apparatus that will improve the quality of life of people with that condition. Consider how the product would be built and marketed. Each team member needs to have a clear role but must be able to contribute to all aspects of the project.

Suggested materials

- computer
- pencil
- paper
- ruler
- balsa wood
- plaster
- papier mâché
- chicken wire
- 3D printer
- cardboard
- poster paper

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Research and feasibility

1. Research genetic diseases and as a group decide which genetic disease will be the focus.
2. Create a table of the causes and effects of the disease.

Genetic disease cause	Effects on part of body	Ideas to help
e.g. Muscular dystrophy Muscle loss	Reduced joint movement	Brace and orthotics for feet
e.g. Haemophilia Blood doesn't clot effectively	Whole body can be bruised easily	1. Creation of children's play suit 2. Creation of some type of buffing edging that could be applied to furniture

3. Find pictures or diagrams of current equipment used, and annotate them with features and characteristics that relate to assisting people living with this disease.

Design and sustainability

4. Sketch potential design solutions (at least two) and annotate the purpose of the apparatus and what it is made of. Describe how it will improve the quality of life for people with this disease. How will it improve on current aids or tools (if any)?
5. Reflect on the materials you would use in real-world construction and comment on the durability and sustainability of the materials.

Create

6. Build a prototype of your design using available construction materials.

Evaluate and modify

7. Reflect on the prototype you have created and its effectiveness to help people with your chosen genetic disease.
8. Discuss as a group the modifications you would make in your solution to increase the effectiveness of design.
9. Present your prototype to the class. Outline the effectiveness of the prototype and demonstrate supporting ideas that show how the prototype would improve the quality of life of a person with this genetic disease.

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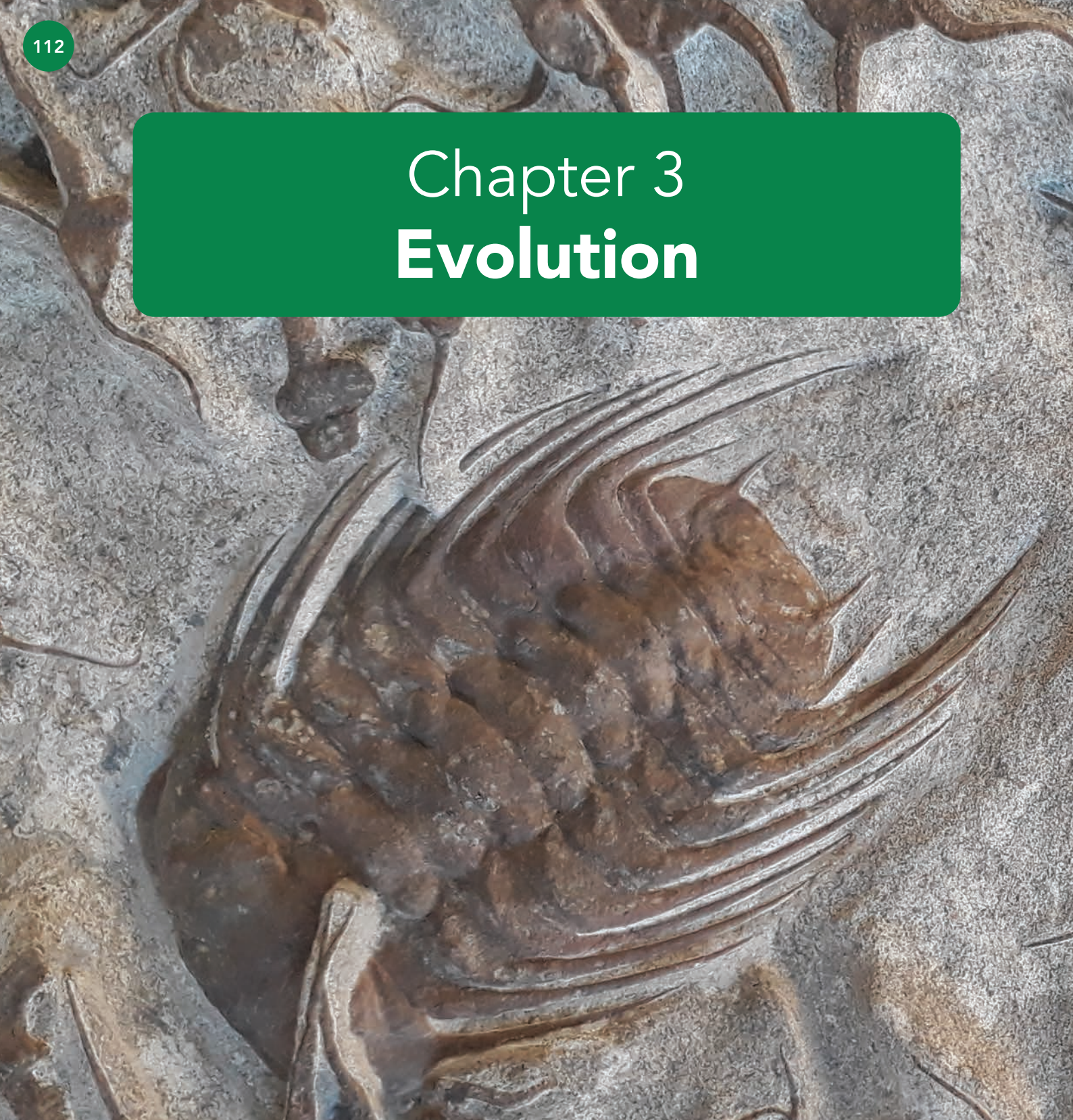

Chapter 3
Evolution

Chapter introduction

Life on Earth has been evolving for billions of years, resulting in an enormous diversity of organisms. But despite the differences, there are also similarities. While koalas, quolls, frogs and dolphins all look different, their skeletons are organised in the same way. This can be explained by evolution: the idea that all organisms on Earth are the living descendants of common ancestors that have changed over a long period. The evidence we see in the fossil record, genetics and other fields of science supports the theory of evolution. In this chapter, we will look at the evidence that supports the theory of evolution and evaluate the key processes involved.

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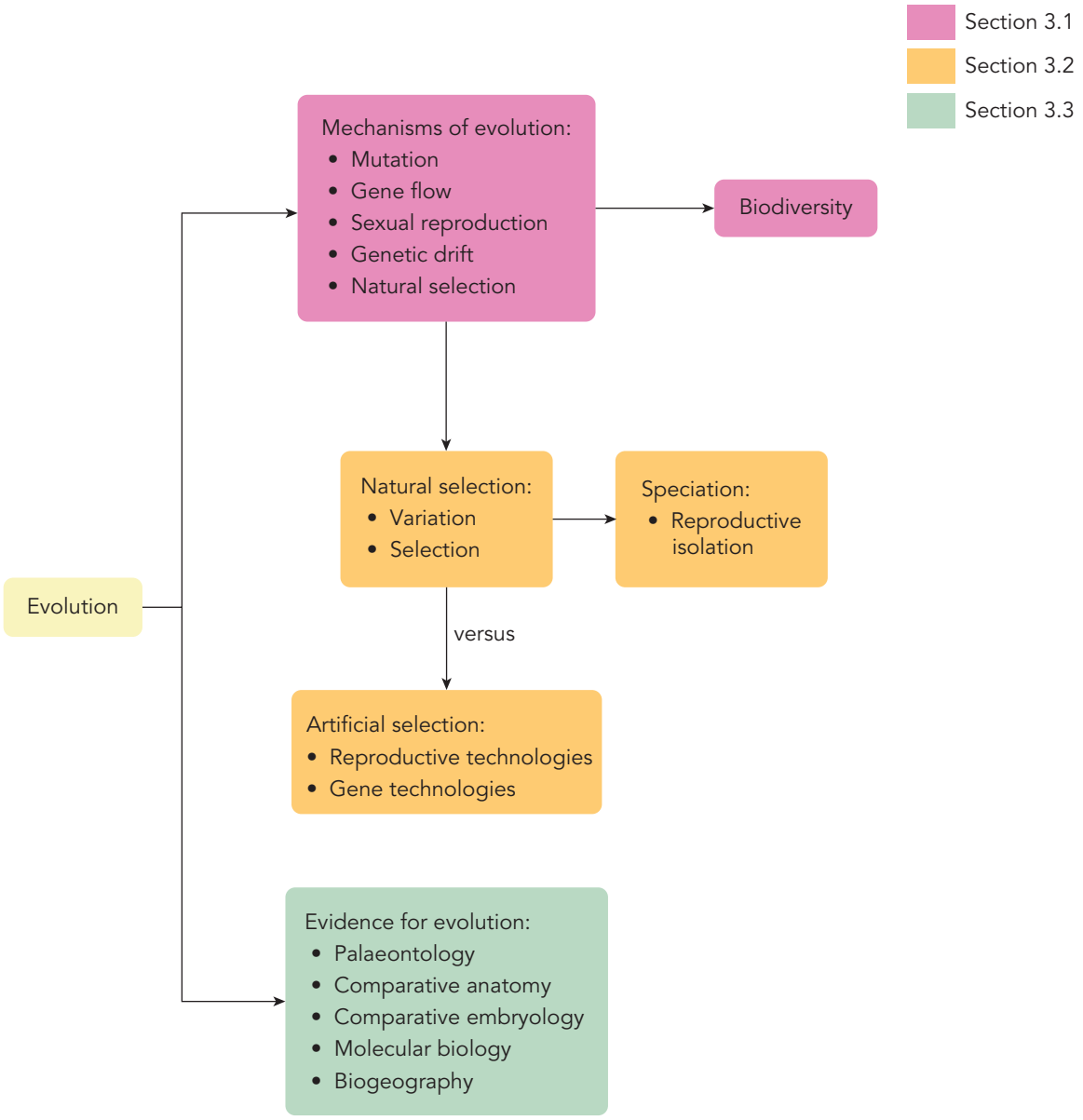
Chapter map



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Curriculum content

Biological sciences	
The theory of evolution by natural selection explains the past and present diversity of living things, including variation within a species, adaptations and speciation	
• natural selection can be used to explain o differences in organisms of the same species at different locations, such as colour, size and shape o adaptations of organisms to changing environments, such as changing colour, size, and resistance to antibiotics and pesticides o how isolation can result in one species becoming a different species over time, such as Australian marsupials, Galápagos finches	3.1, 3.2
• the importance of maintaining genetic diversity	3.1
• analysing evidence for the theory of evolution by natural selection including the fossil record, chemical and anatomical similarities, and geographical distribution of species	3.3

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Glossary terms

absolute dating
adaptation
allele frequency
analogous structures
artificial selection
biodiversity
biogeography
biostratigraphy
biota
bottleneck effect
convergent evolution
direct (evidence)
divergent evolution
DNA hybridisation
ecosystem diversity
endangered
endemism
evolution
evolutionary tree
extinct
fertile
fossil
fossil record
fossilisation
founder effect
gene flow
genetic diversity
genetic drift
genetic variation
half-life
homologous structure
index fossil
indirect (evidence)
mass extinction
megafauna
natural selection
population (ecological)
radioisotope
relative dating
reproductive isolation
selection pressure
selective advantage
selective breeding
speciation
species
species diversity
stratigraphy
trace fossil
variation
viable

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3.1 Evolution

Learning goals

At the end of this section, I will be able to:

1. Describe how evolution can take place through five key drivers.
2. Explore how biodiversity has changed over time.

WORKSHEET
Mechanisms for evolution

Evolution is a complex process involving genetic changes that accumulate over long periods within **populations**. These changes, in conjunction with environmental influences, give rise to phenotypic variation among individuals. The primary source of **genetic variation** is mutation, which introduces new genetic material into a population. Additionally, meiosis and the random fertilisation of gametes during sexual reproduction contribute to the reshuffling and mixing of existing genetic material.

Within a population, individuals possessing phenotypic traits that enhance their ability to survive and reproduce in a particular environment have a higher likelihood of passing on their advantageous alleles to their offspring. Over time, these advantageous alleles become more prevalent in the population, causing a shift in **allele frequency**.

The effect of these genetic changes, driven by natural selection, genetic drift, migration and other evolutionary forces, leads to the changes in populations and the potential emergence of new species.

evolution change in the genetic composition of a population over successive generations, which may result in the development of new species

population (ecological) a group of a particular species living and interbreeding in the same geographical area

genetic variation the differences in DNA sequences between individuals within a population

allele frequency the relative proportion of a specific allele within a population

variation the range of differences or diversity in traits, characteristics or genetic make-up among individuals

Mechanisms of evolution

Evolution can take place through five key drivers:

- mutation
- gene flow
- genetic drift
- natural selection
- sexual reproduction – including meiosis and random fertilisation (as discussed in Chapter 2).

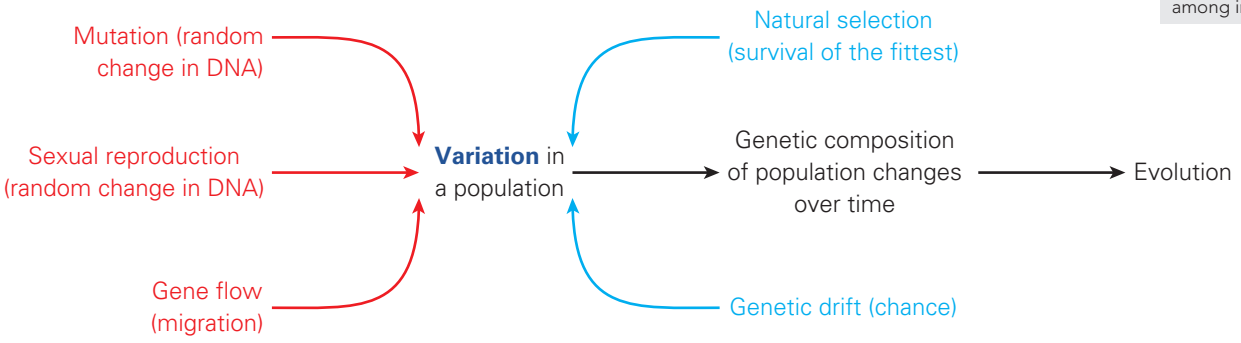
Mutation (random change in DNA)
Sexual reproduction (random change in DNA)
Gene flow (migration)
Variation in a population
Natural selection (survival of the fittest)
Genetic drift (chance)
Genetic composition of population changes over time
Evolution

Figure 3.1 Changing genetic information changes the variation within a population. This leads to an overall change in the genetic composition of a population, which means evolution is occurring.

Mutation

For evolution to occur, there must be a change in the genetic make-up of at least one individual. Recall from Chapter 2 that a mutation is a spontaneous or induced change in the genetic sequence of an organism's DNA. If present in gamete cells, mutations are heritable and can be passed down to future generations (see Figure 3.2).

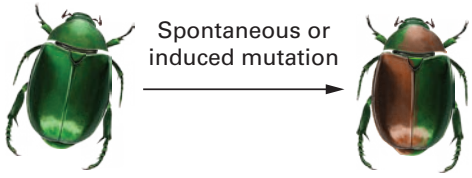

Figure 3.2 A spontaneous or induced mutation in a gamete can cause a change in the DNA code passed on to the next generation, contributing to evolution.

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Mutation is a random process, and changes can occur anywhere in the DNA. Mutations may have various effects on the phenotype of organisms, ranging from no change to large changes. These large changes include genetic diseases that are associated with a loss of function. Since genetic disease reduces an individual's chance of survival, these are often not passed on to future generations. However, in specific circumstances, mutations that are usually detrimental or harmful can be beneficial.

Mutations are the ultimate source of genetic variation as they introduce new alleles. If the mutation is advantageous and occurs in the gametes, it may lead to a shift in the genetic composition in the population. This links to another driver of evolution called natural selection, which will be covered later. Along with natural selection, mutations are one of the main drivers of evolution, and without them, evolution cannot occur.

Genetic disease	Some of the outcomes
Albinism	No or little colour in skin, hair and eyes Reduced sun protection
Cystic fibrosis	Thicker mucus lining organs Respiratory and other health paroblems Fatigue
Duchenne muscular dystrophy	Progressive muscle weakness
Haemophilia	Blood cannot clot properly Abnormal bleeding
Sickle cell anaemia	Sickle-shaped red blood cells can interrupt blood flow Pain and fatigue Resistance to malaria, which is beneficial in areas where malaria is common

Table 3.1 Some examples of genetic diseases caused by mutations

Did you know? 3.1

Figure 3.3 Marble Bar, in the Pilbara region of Western Australia, is Australia's hottest town. Temperatures more than 45°C are common in December and January.

Figure 3.4 Breath mints contain menthol, which activates the same receptor that detects cool or cold temperatures.

Human adaptations to temperature

Researchers have found that approximately half of the Aboriginal population of Western Australia have a mutation that makes them produce a different amount of thyroxine, a hormone that regulates metabolism, including body temperature. This provides an advantage in areas that can regularly exceed 45°C.

Contrastingly, a gene that is associated with cold temperatures has been found in higher frequency in European populations living in (or originating from) cold, northern climates. The gene, called *TRPM8*, codes for a receptor that detects and responds to cold temperatures. The same receptor is also activated by menthol, causing the 'cooling' sensation we get when consuming mints or mint-containing foods.

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Gene flow

Another way genetic variation can be introduced into a population is through **gene flow**, which is enabled by migration. Migration is the movement of individuals from one population to another, while gene flow specifically refers to the movement of alleles from one population to another. Gene flow can only occur between separate populations of the same species because they must be able to interbreed and reproduce (see Figure 3.5).

gene flow the movement of genetic information from one population to another through migration

Gene flow can occur through different kinds of events, such as seed dispersal, animals moving to different areas or movement forced by natural disasters such as fires or floods.

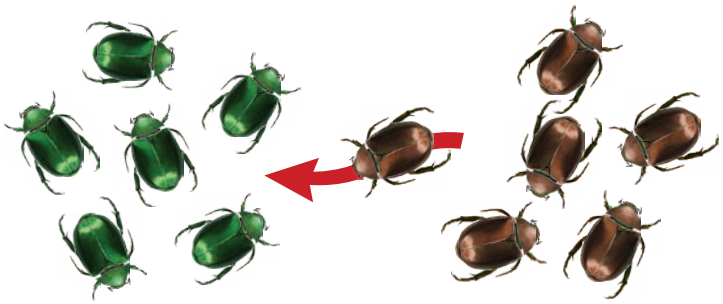

Figure 3.5 Unlike alleles created by mutations, the alleles brought in by gene flow already exist within the species but are absent from some populations.

Making thinking visible 3.1

Claim, support, question: Koalas and gene flow

While the koala is one species, there are five distinctly different genetic populations across Australia's east coast. The loss of genetic diversity from small, fragmented koala populations increases their risk of extinction due to both inbreeding and an inability to adapt when the environment changes. Maintaining genetic diversity in koalas is critical to their survival. This can be achieved by maintaining large, interconnected natural populations or through wildlife translocation, which is an artificial form of gene flow.

Wildlife translocation is being used with increasing frequency to conserve a variety of species, but it is also controversial, even among conservationists. Potential problems include the spread of diseases, increased stress and mortality of relocated animals and negative impacts on the organisms at release sites.

Using your prior knowledge and the information provided, make a **claim** about wildlife translocations.

Provide evidence to **support** your claim.

Pose a **question** related to your claim or supporting evidence. What remains unexplained or requires further investigation?

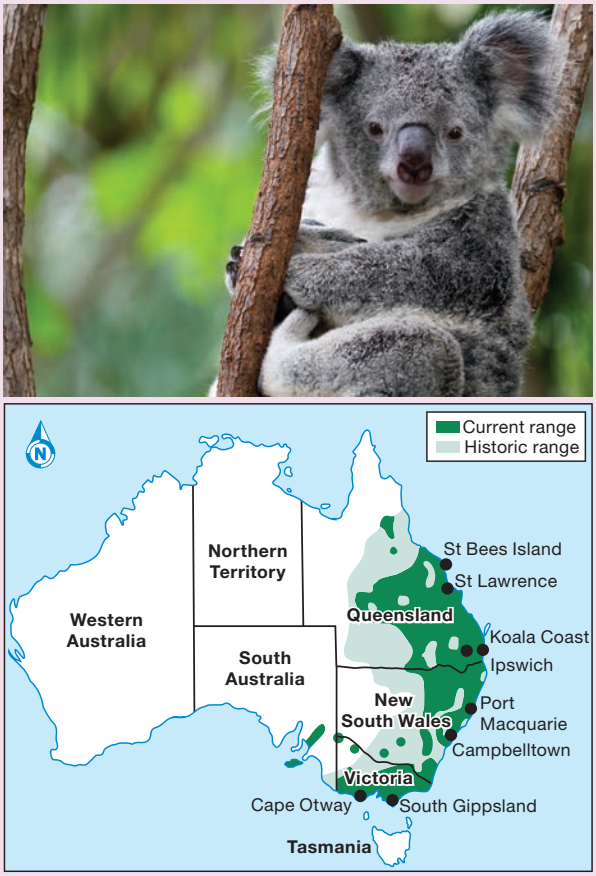

Figure 3.6 The survival of koalas depends on maintaining gene flow between increasingly isolated populations.

The *Claim, support, question* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Genetic drift

genetic drift the random change in allele frequencies in a population from generation to generation

founder effect the decrease in genetic diversity that occurs when a population is descended from a small population that separated from a larger one

bottleneck effect the decrease in genetic diversity resulting from a rapid reduction in the size of a population due to events such as natural disasters or human activities such as overhunting

Genetic drift is random changes in allele frequencies in a population over time. Genetic drift is always happening in a population, as chance outcomes of meiosis, crossing over and fertilisation affect the genetic composition of each new generation. The effects of genetic drift are greater in smaller populations. Two extreme examples of genetic drift are the **founder effect** and the **bottleneck effect**.

The founder effect occurs when a small group of individuals separates from a larger population to establish a new colony. By chance alone, the allele frequencies in this small founder population are likely to differ from those in the original population, leading to reduced genetic variation and potentially unique traits in the new group.

A population 'bottleneck' occurs when the size of at least one generation of the population is severely reduced, perhaps by a chance event such as an environmental disaster or because of human activities such as habitat destruction or overhunting. This results in the deaths of many organisms, leaving behind a small, random population of survivors (see Figure 3.8). The genetic diversity of this surviving group is often greatly reduced, as only a limited set of alleles is carried forward.

Figure 3.7 Norfolk Island, which is located between New Zealand and New Caledonia, was used as a penal colony and then abandoned in 1855. Most present-day islanders are the descendants of a founder population made up of a small number of the descendants of the HMS *Bounty* mutineers and Tahitian women who relocated from Pitcairn Island in 1856. The founder effect has significantly affected the height of the islanders and the prevalence of cardiovascular diseases in their community.

The bottleneck effect and the founder effect both result in populations with an allele frequency that differs in a random way from their source or original population. In both cases, because the remaining population is much smaller than the original population, genetic drift is amplified, and there is also less genetic diversity. These factors may result in the new population becoming genetically distinct from the original population over time, and this can lead to reduced adaptability, increased inbreeding and a higher risk of extinction.

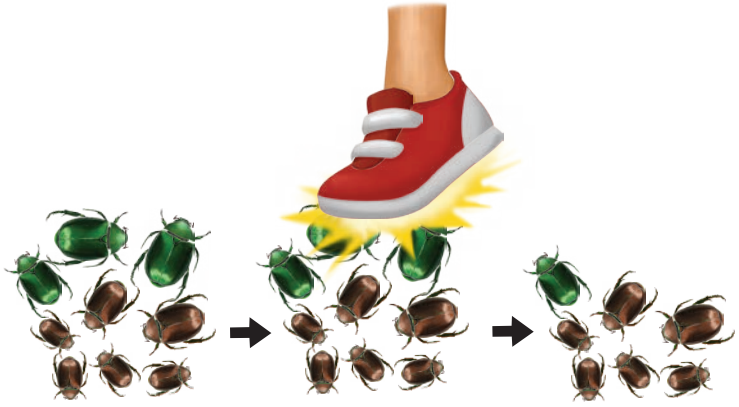

Figure 3.8 Someone standing on some beetles by accident is a random or chance event. If the population size is greatly reduced to the extent that the genetic composition of the beetles' population has changed, this is an example of how the bottleneck effect contributes to evolution.

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Did you know? 3.2

The black robin bottleneck

Figure 3.9 The black robin (*Petroica traversi*)

Before European colonisation, black robins (*Petroica traversi*) were common on Rēkohu/Chatham Islands, New Zealand. However, their population crashed once rats invaded the archipelago, and by 1976, only seven birds survived. The birds were moved to a predator-free island, but scientists were not confident that the population, which had only one breeding pair (called Old Blue and Old Yellow), would recover due to the severe genetic bottleneck. However, as of 2022, there are approximately 290 surviving birds, and surprisingly, although the bird is certainly one of the most inbred in the world, genome analysis has shown that the frequency of harmful genetic alleles in the population did not increase as a result of the bottleneck.

VIDEO
Natural selection

Natural selection

Individuals in a population show a wide range of phenotypes. Some of these phenotypes may provide **selective advantages**, meaning those individuals are more likely to survive and reproduce, passing on those advantageous alleles to their offspring. This is **natural selection**. Often, the term 'survival of the fittest' is used to describe this: the organisms that are best suited to their environment – that is, have the best **adaptations** – are more likely to survive and pass on their genetic information. For example, look at Figure 3.10. These beetles live in the leaf litter on the forest floor and have natural variation in their colour that is heritable: they can be green or brown. The birds eat more green beetles, because they are easier to spot. The green beetles are at a selective disadvantage (they have a lower fitness value), so fewer green beetles will survive to reproduce and fewer alleles that code for green colouring will be passed on to the next generation. The brown beetles are better adapted to their environment and have the better colour for survival (that is, the brown beetle is at a selective advantage; it has a higher fitness value). Alleles that code for brown colouring are more likely to be passed on to the next generation.

selective advantage
the characteristic of an organism that enables it to survive and reproduce better than other organisms in a population

natural selection
a process in which organisms whose phenotype is best adapted to their environment are more likely to survive and reproduce

adaptation
a characteristic that contributes to an individual's ability to survive in its environment

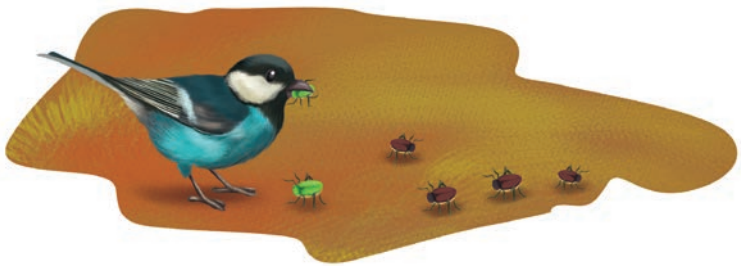

Figure 3.10 Alleles within a population are less likely to be passed on to the next generation if they are disadvantageous. Brightly coloured beetles are more likely to be spotted by predators, which puts these organisms at a disadvantage.

Figure 3.11 Cane toads in rural areas have larger parotid (toxin) glands than those in urban areas. This may be because bush toads are at a higher risk of predation, so it is a selective advantage to have glands that can produce more bufotoxin.

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Practical 3.1

Modelling genetic drift, natural selection and gene flow

Be careful
Do not consume food items.

Aim

To simulate genetic drift, natural selection and gene flow in a population of jellybeans and analyse the consequences of each.

Materials

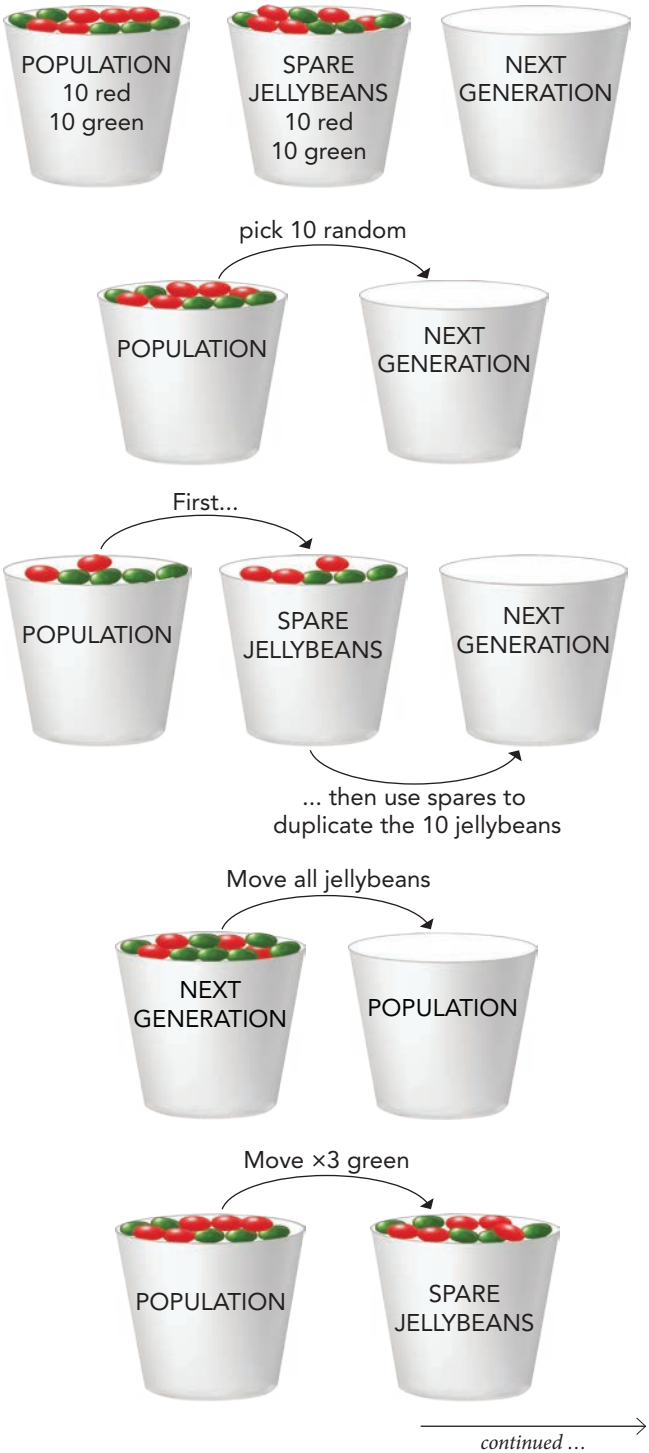
- jellybeans: 20 red, 20 green and 20 blue (or anything similar, e.g. coloured paper)
- 3 cups: one labelled 'Population', one labelled 'Next generation' and one labelled 'Spare jellybeans'

Method for genetic drift

1. Copy the results table into your science book.
2. Place 10 red jellybeans and 10 green jellybeans in your 'Population' cup. These represent the alleles of the population. Place all other jellybeans in the 'Spare' cup for unused jellybeans. Record the current population in your results table as your first generation.
3. With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them in the 'Next generation' cup. These are the alleles that will be passed on.
4. Throw the remaining jellybeans from your 'Population' cup into the 'Spare' cup. Duplicate the 10 jellybeans (e.g. if you picked out four red and six green, pick out another four red and six green from the 'Spare' cup and place them in the 'Next generation' cup).
5. Record this in the next row of your results table.
6. Take the new generation alleles (jellybeans) from the 'Next generation' cup and place into the 'Population' cup.
7. Repeat steps 3–6 until you have 10 rows of data or until one colour is eliminated.

Method for natural selection

1. Start by repeating steps 1 and 2 of the method for genetic drift.
2. Imagine that green has a selective disadvantage (the opposite of a selective advantage). Pick out three green jellybeans from the population and move them into the cup for spare jellybeans.
3. Repeat steps 3–6 of the method for genetic drift until you have 10 rows of data or until one colour is eliminated.



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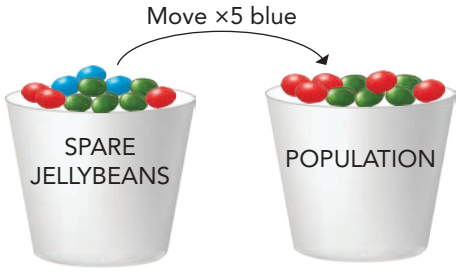
Results for genetic drift and natural selection

Generation	Number of alleles	
	Red	Green
1	10	10

Method for gene flow

1. Copy the results table into your science book.
2. Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
3. Add five blue jellybeans into the 'Population' cup.
4. Repeat steps 3–6 of the method for genetic drift until you have 10 rows of data or until two colours are eliminated.



Results for gene flow

Generation	Number of alleles		
	Red	Green	Blue
1 (before migration)	10	10	0

Discussion

1. Plot your results on a graph. There should be one each for the genetic drift, natural selection and gene flow simulations.
2. Describe what happened in each case. How do the results compare to what you would expect for each process?
3. Did your results show any colour becoming extinct in your population?
4. Compare your results for genetic drift with those of another classmate or group. Account for any contradicting trends in the results.
5. Propose what step 6 could represent in the genetic drift simulation.
6. Propose what step 2 could represent in the natural selection simulation.
7. Propose what step 3 represents in the gene flow simulation.
8. Imagine that the introduced blue allele also had a selective advantage in the gene flow simulation. How would you simulate this scenario?
9. Imagine that there was a mutation in one of the jellybeans that turned it orange. How could this affect future generations?
10. What assumptions have we made about the red, green and blue alleles in this simulation?
11. Can reliable conclusions and predictions be drawn from the results? Justify your answer.
12. List some limitations of this simulation compared to what happens in real life. Justify your response.
13. What are some ways in which the simulations can be improved?

Quick check 3.1

1. **Define** the terms 'evolution', 'population', 'variation' and 'adaptation'.
2. **Identify** the five drivers of evolution.

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Try this 3.1

Drivers of evolution

Summarise the five drivers of evolution you have learned by copying and completing the following table.

Mechanism	Definition	Contribution to evolution
Mutation		
Gene flow		
Genetic drift		
Natural selection		
Sexual reproduction		

Biodiversity as a function of evolution

biodiversity the variety of life on Earth, including the diversity of species, the genetic differences within a species and the ecosystems where species are found

species diversity the number and abundance of different species in a given area

genetic diversity the number of different alleles of genes in a population

ecosystem diversity the variation in ecosystems in a given area

Biodiversity (biological diversity) refers to the variety of life on Earth. It includes **species diversity** (the number of different species within an ecosystem), **genetic diversity** (the number of different alleles of genes in a population) and **ecosystem diversity** (the variation in ecosystems in a given area). Over time, populations within a species can become so different that they become a different species, increasing biodiversity. Therefore, it is evolutionary processes that have resulted in the biodiversity we see today.

Australia's unique biodiversity is best explained by isolation. Australia was once part of a supercontinent called Gondwana that even earlier was the southern part of a giant land mass called Pangaea. Gondwana was made up of the continents and countries that we know today as South America, Africa, Australia, India and Antarctica. Gondwana is thought to have begun breaking up approximately 140 million years ago. As a result, our plants and animals have been isolated over a long period of time from the plants and animals of other continents and land masses.

As the continents moved across the surface of Earth, so too did their assemblages of plants and animals. This not only created geographical barriers (like oceans, mountain ranges and large rivers), but over time it also brought new combinations of species together.

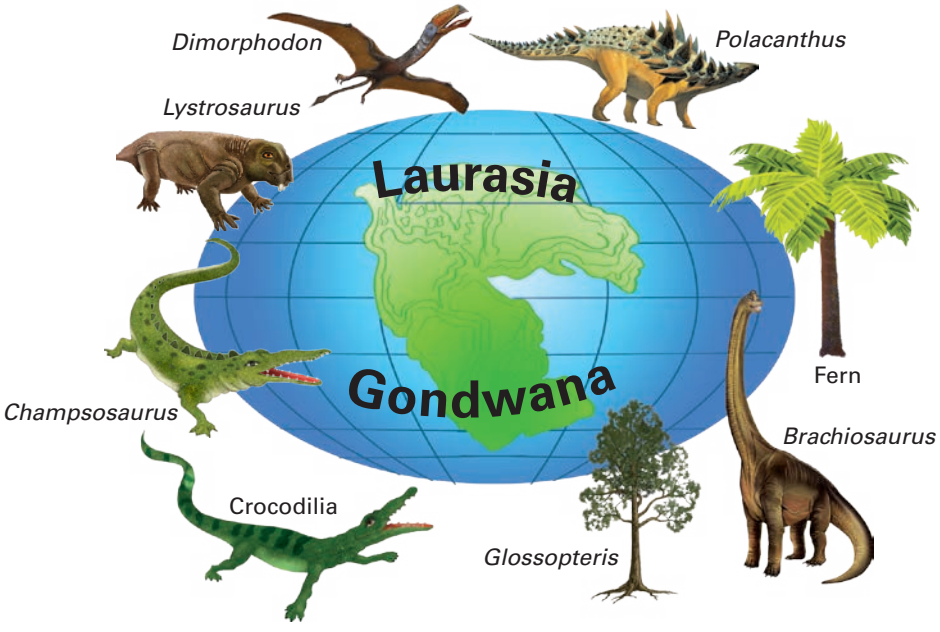

Figure 3.12 This map shows the supercontinent Pangaea before it separated into a northern Laurasia and a southern Gondwana.

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Quick check 3.2

1. **State** what is meant by the term 'biodiversity'.
2. **Recall** what supercontinent Australia was once part of.
3. **Explain** how the movement of continents led to increased species diversity.

Biodiversity through time

Our understanding of the origin of life on Earth is based upon the scientific evidence of the fossil record and genetic comparisons to modern life forms. Earth is approximately 4.5 billion years old, and the most primitive cells first developed some 3.5 billion years ago. Although life appeared early in Earth's history, evolution beyond the simple cell stage did not occur until much later – approximately 600 million years ago. Since then, the biodiversity that exists on Earth has fluctuated in response to environmental changes. Figure 3.13 shows a timeline of the major stages in the development of life on Earth, highlighting key events that shaped the diversity we see today. Among these events are five **mass extinctions** periods, during which large numbers of species disappeared over thousands or even millions of years. One of the most well known of these is thought to have been triggered by an asteroid impact, which may have led to the extinction of the dinosaurs. An asteroid is suspected to be involved in just one case of mass extinction, but volcanic activity has been implicated in at least four. Here are some hypothesised causes for the biggest mass extinctions on Earth:

mass extinction a rapid, widespread loss of biodiversity, with many species going extinct in a short timeframe

- volcanic activity
- climate change
- changes in deep-ocean oxygen levels
- changes in sea level.

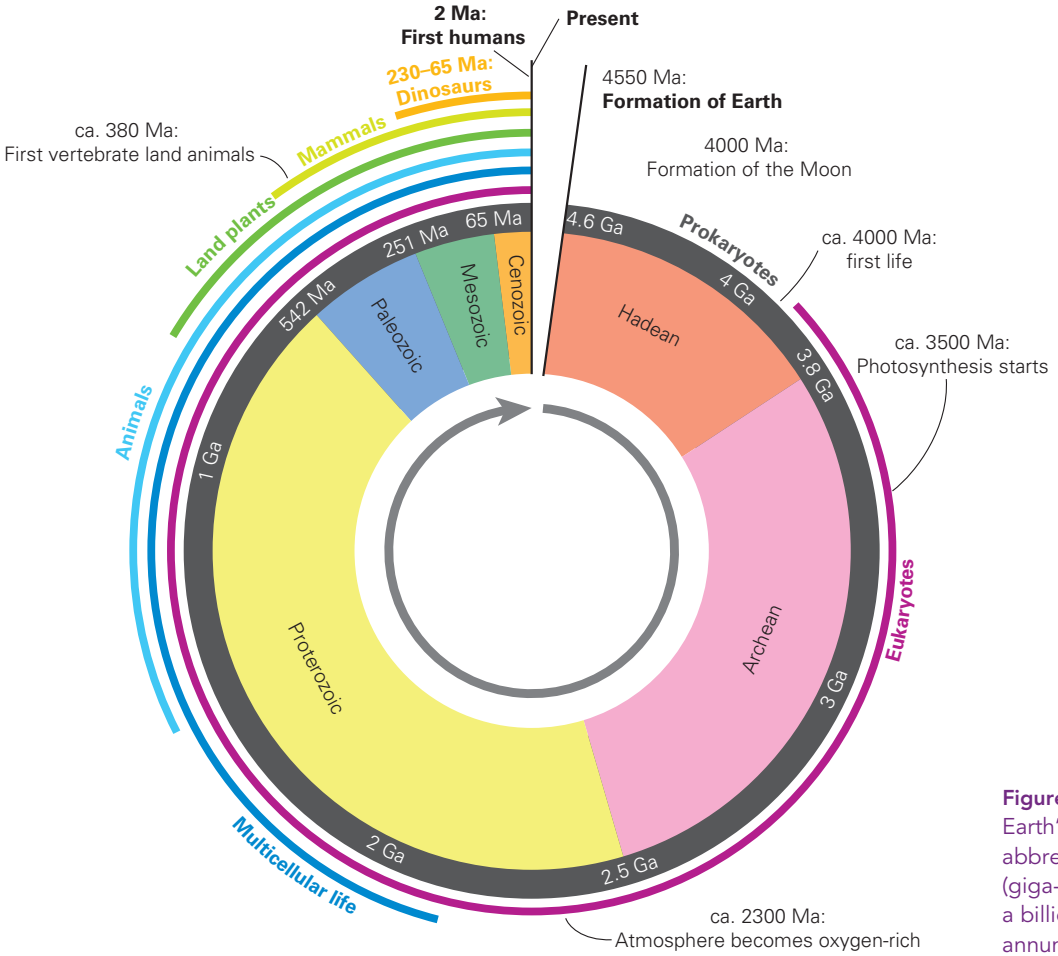

Figure 3.13 A timeline of Earth's history (ages are abbreviated from Latin: Ga (giga-annum) represents a billion years, Ma (mega-annum) is a million years)

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Figure 3.14 Heard Island and the McDonald Islands (HIMI), located about 4100 km southwest of Perth, are remote volcanic islands in the Southern Ocean whose active volcanism has shaped their unique biodiversity. Continuous eruptions and geothermal activity create varied habitats, supporting life in harsh sub-Antarctic conditions. Volcanic heat enables mosses, lichens and small plants to thrive on otherwise ice-covered landscapes, while the islands' isolation provides undisturbed breeding grounds for seals, penguins and seabirds.

biota
all the living organisms found within a particular region or ecosystem

endemism
a state of being confined to a small, defined geographic location

megafauna
large animals with a body mass of over 45 kilograms

A combination of the causes listed previously in this section may have contributed to mass extinctions, which caused major and rapid changes in the Earth's **biota**. If there is sufficient genetic variation in a species when an environmental change occurs, such as when there is a volcanic eruption, some organisms within a population will be better suited to that new environment than others. The survival of the better-adapted individuals will result in a change in the genetic composition of the species' population, resulting in their evolution over time.

The biodiversity of Australia

Australia's biodiversity is rich and unique; estimates suggest that between 7% and 10% of all species on Earth are found here. This unique biodiversity developed in isolation over millions of years, producing a high level of **endemism**. This means a large number of species found in Australia are unique to the region and are not naturally found anywhere else in the world. This high level of endemism is attributed to Australia's geographical isolation and long evolutionary history, which allowed the development of species adapted to the specific Australian environment. Australia's biodiversity is also influenced by its unique environmental conditions, which include high fire frequency, nutrient-poor soils, climatic variability and a relatively flat landscape.

Australia's landscape has been shaped over tens of thousands of years by natural events, ecological processes and human activity. First Nations Australians and, later, European settlers have had significant impacts on the continent's biodiversity. It is believed that the first people arrived in Australia via South-East Asia, during a time when lower sea levels created land bridges between landmasses. Scientific evidence suggests that humans have lived on the Australian continent for at least 65 000 years.

Aboriginal and Torres Strait Islander Peoples developed sophisticated and sustainable land management practices, such as fire management (often called fire-stick farming), which helped maintain healthy ecosystems and promote biodiversity. In contrast, European colonisation brought widespread habitat destruction, the introduction of invasive species and unsustainable land use, all of which caused major environmental disruption and long-term ecological change.

Australia was once home to **megafauna**, which were large land animals that evolved millions of years after the dinosaurs became extinct, and included:

- *Diprotodon optatum*, the largest marsupial ever to have lived, with a shoulder height of 1.8 metres and weighing close to 3 tonnes
- *Palorchestes azael*, a marsupial about the size of a horse
- *Thylacoleo carnifex*, a 1.5-metre-long marsupial lion; and
- *Wonambi naracoortensis*, a 50-kilogram, 5-metre-long snake.

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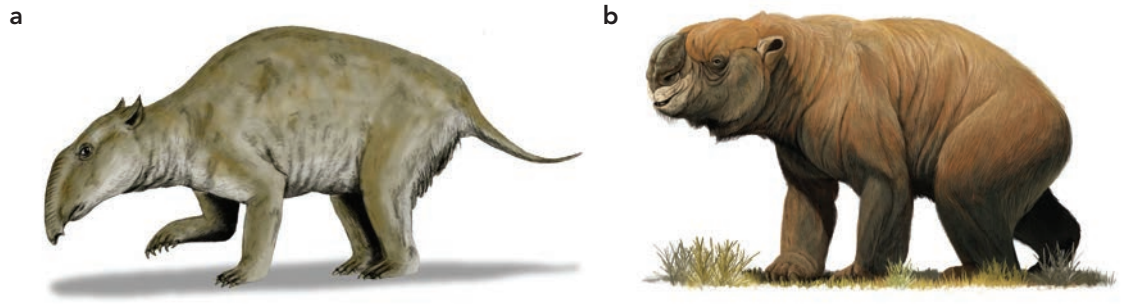

Figure 3.15 Two extinct species of Australian megafauna: **(a)** *Palorchestes azael* and **(b)** *Diprotodon optatum*

The fossil record and rock art suggest that these species coexisted with Aboriginal and Torres Strait Islander people for tens of thousands of years. The cause of their extinction is unconfirmed but is thought to have resulted from a combination of factors, including climate change, shifting ecosystems, possible overhunting and changing water and vegetation availability.

Research indicates that increasing aridity, more frequent fires and reduced water sources may have significantly impacted megafaunal habitats and diets, contributing to their decline. Analysis of fossilised teeth has found that climate change had a significant impact on megafaunal diets. These changes highlight the complex interactions between climate, ecosystems and human practices in shaping the Australian environment over millennia.

Explore! 3.1

Ancient artwork

First Nations Peoples have a cultural heritage closely tied to their environment. Their artwork, including rock engravings and paintings, reflect their connection with the land and its biodiversity.

These artworks often depict changes in plants and animals over time, including the presence of megafauna.

Use the internet to research First Nations art to find specific examples of rock engravings, paintings and other forms of art that depict changes in plants and animals over time. Focus on artwork that illustrates megafauna.

For each example, provide the following details:

- when it is believed the artwork was created
- where the artwork is found (for example, specific rock sites, regions)
- a description of the artwork, including the plants and animals depicted.

Once you have selected your examples, explain how the artwork may be used to indicate changes in plants and animals over time.

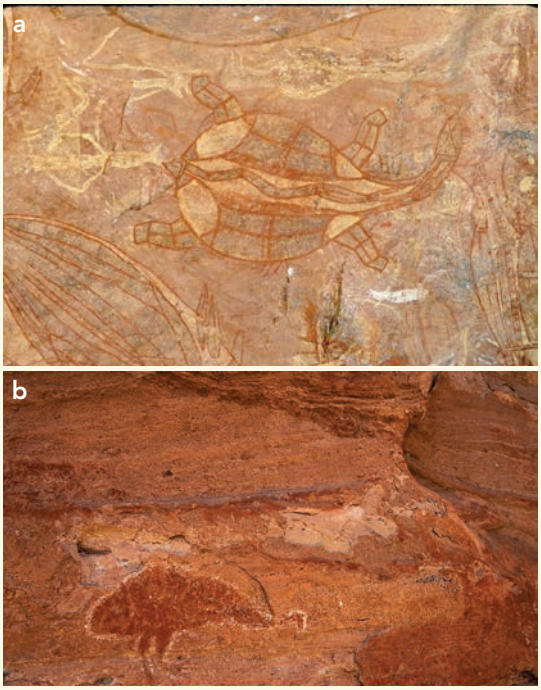

Figure 3.16 Rock art at **(a)** Ubirr, Kakadu National Park and **(b)** Keep River National Park

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Maintaining biodiversity

Maintaining biodiversity is extremely important. A reduction in biodiversity can have huge impacts on ecosystems and result in the loss of species that are beneficial to other species, including humans. Maintaining diversity means keeping a full range of species in ecosystems in order to conserve the variety of organisms on Earth. Species are considered **endangered** if they meet the criteria set by the International Union for Conservation of Nature (IUCN). These include species whose numbers have experienced a reduction of 70% in a decade and species with fewer than 250 mature individuals living in a single population.

endangered
a species that is in danger of becoming extinct

extinct
a species that has no living members

Figure 3.17 Rock art depicting a hunter and a giant kangaroo in Anbangbang Shelter at Burrunggui, Kakadu National Park

Endangered species are at risk of becoming **extinct**, especially if there is not enough genetic variation in the population. However, species can be at risk even if their population is large. Changes in the environment that may cause extinction include new diseases, new predators, competition with a better-adapted species and loss of habitat.

Making thinking visible 3.2

Chalk talk: The coral ark

In 2023, the Great Barrier Reef Legacy, located in Port Douglas, established the world's first facility dedicated to coral conservation, the Living Coral Biobank. The project aims to conserve the genetic diversity of hard coral species by collecting, cataloguing and storing living fragments, tissues and genetic samples from coral species.

Read the following quote from Dr Dean Miller, Managing Director of Great Barrier Reef Legacy.

"We will collect all known corals and keep them alive in land-based facilities for their ultimate conservation."

Dr Dean Miller

Figure 3.18 Despite covering less than 0.1% of the world's ocean floors, coral reefs provide a home for millions of different species.

1. Take a moment to reflect on the quote and write down any thoughts that come to mind.
2. Discuss your ideas as a group, sharing your individual perspectives on the quote.
3. Think about how your classmates' responses connect with your own thoughts, and write down any questions that arise as you listen to their feedback.

The *Chalk talk* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Figure 3.19 Only a few dibblers (*Parantechinus apicalis*) remain in the wild, with populations limited to coastal habitats in south-western Australia and Boullanger and Whitlock islands. Perth Zoo's successful breeding program, initiated in 1997, has led to numerous releases into protected areas. Recent efforts have also introduced dibblers to Dirk Hartog Island, where signs of successful breeding have been observed. The next goal is to ensure these reintroduced populations thrive in their natural habitats.

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There are ways that humans can help to maintain biodiversity.

Gene banks are facilities where genetic material, such as seeds, tissues and DNA samples, are stored under controlled conditions. Seed banks, a common type of gene bank, preserve the genetic material of plants by storing seeds at low temperatures to maintain their viability for future use. This helps conserve the genetic diversity of crops, wild plants and endangered species, providing a vital resource for research, breeding programs and restoration projects.

Insurance populations refer to living populations that are maintained to preserve genetic diversity outside their natural habitats, often as a safeguard against extinction. This can include captive breeding programs in zoos, aquariums and botanical gardens, where individuals are bred to retain genetic variability. Insurance populations are also created through cryopreservation of embryos, sperm and eggs, which can be used to reintroduce genetic diversity into wild or captive populations in the future.

Figure 3.20 The Australian Grains Genebank (AGG), located in Horsham, Victoria, preserves genetic diversity in Australian grain crops like wheat, barley and pulses, holding over 200 000 seed samples from around the world. It supports crop improvement and breeding programs, helping to develop new varieties resistant to pests, diseases and climate change.

Explore! 3.2

Conservation of Australian species

Australia has the fourth-highest level of species extinctions in the world and is in the top three for critically endangered animals. Since 2016, 202 animal and plant species have been listed as threatened, including the short-billed black cockatoo, western quoll and the black-flanked rock wallaby. Conduct some research to answer the following questions.

1. Choose an endangered Australian species and research conservation efforts put into place for the species. These may include education programs, captive breeding, legal protection of habitats and ecosystems created artificially.
2. Many of today's species have survived by adapting where other species, less well adapted, died out. Do you think we should try to protect endangered species to preserve biodiversity? Why?

Figure 3.21 A short-billed black cockatoo (*Zanda latirostris*)

Quick check 3.3

1. **Define** the terms 'biodiversity', 'endangered' and 'extinct'.
2. **Explain** the link between biodiversity and evolution.
3. **Name** one change in the environment that may lead to the extinction of a species.
4. **Discuss** how humans have affected biodiversity and therefore evolution.

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Making thinking visible 3.3

Connect, extend, challenge: Cat curfew

Australia has the highest mammal extinction rate in the world: 34 mammal species have disappeared since European settlement. Introduced predators, particularly feral cats and the European red fox, have caused most of these extinctions. Extinctions have been particularly high in arid and semi-arid regions. One report found that every year each individual feral cat in Australia kills 390 mammals, 225 reptiles and 130 birds. Combined with those killed by domestic cats, over two billion native animals are killed by cats each year in Australia.

In many Australian local council areas, cat owners must now keep their pets on their own land. In some areas, there is a curfew so cats are not allowed outside after dark; in other areas, cats are not allowed outside at all.

After reading about mammal extinctions in Australia, reflect on the following:

1. How do the concepts and details connect to your existing knowledge?
2. Which new insights did you gain from the text that expanded your understanding or encouraged you to consider new perspectives?
3. What questions arise for you after processing this information?

The *Connect, extend, challenge* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Go online to access the interactive section review and more!

Section 3.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 3.1 questions

Remembering

1. **Define** the terms 'evolution' and 'population'.
2. **Name** one extinct Australian species.
3. **Name** one species deemed critically endangered within Australia.
4. **Define** the term 'variation' and give four different examples of variation within a species not provided in the text.
5. **Recall** where variation in a population comes from.

Understanding

6. **Explain** how mutations contribute to variation within a species and, consequently, evolution.
7. **Explain** how gene flow can contribute to a change in the allele frequency of a population.
8. **Summarise** how a change of only one nucleotide in DNA can result in a different phenotype and eventually cause evolution.

Applying

9. **Identify** an example of variation within a species that:
   a) increases an individual's chances of survival
   b) decreases the species' chance of survival
   c) does not affect the species' chance of survival.
10. **Explain** how extinctions can stimulate new biodiversity among species.

Analysing

11. **Distinguish** between species diversity and genetic diversity.
12. **Distinguish** between extinct species and endangered species.

Evaluating

13. **Discuss** why genetic biodiversity is important for the survival of a species.
14. In Earth's past, some species have been wiped out after an environmental change. **Decide** if this suggests the species had low or high genetic biodiversity and give reasons why this would occur.

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3.2 Natural and artificial selection

Learning goals

At the end of this section, I will be able to:

1. Recall the steps in the process of natural selection.
2. Outline the factors that lead to speciation.
3. Describe some examples of artificial selection.

WORKSHEET
Natural selection

In Section 3.1, you read that there are five drivers of evolution: mutation, gene flow, genetic drift, natural selection and sexual reproduction. In this section, natural selection will be considered in more detail.

In 1831, at the age of 22, the naturalist Charles Darwin set out on a five-year voyage around the world to study and collect animal, plant and rock specimens. He visited the remote Galápagos Islands off the coast of Ecuador and recorded the plant and animal species of the islands.

Initially, Darwin took little interest in his collection of finches from the islands, but this changed when the eminent ornithologist John Gould classified them as 12 new species. Gould had noticed that they showed great variation in their beaks. It was his observations that helped Darwin develop his theory of evolution.

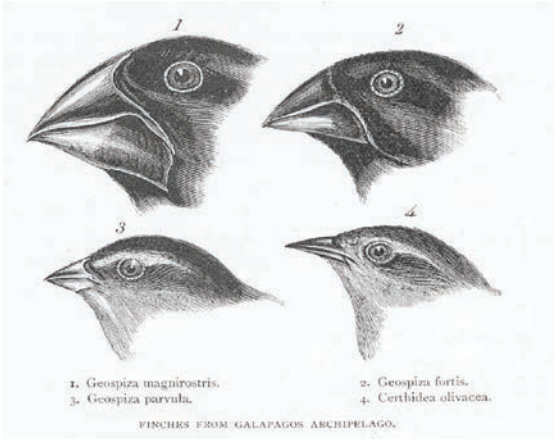

Figure 3.22 On the Galápagos Islands, finches evolved based on different food sources.

Figure 3.23 John Gould published the first comprehensive survey of birds in Australia. He was accompanied by his wife, Elizabeth Gould, who was a talented ornithologist and illustrator in her own right. This image was taken from his book *The Birds of Australia*, which was published from 1840 to 1848 in seven volumes.

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Darwin speculated that although the different islands had similar animals and plants, many species seemed to have specialised features that were particularly suited to their local environments. For example, the different finch species had beaks suited to eating the food source that was available in the habitat they occupied on their island. Darwin explained how species change over time, using the theory we know today as 'natural selection'.

Did you know? 3.3

Galápagos tortoises

Galápagos tortoises have variations in their shell shapes and sizes. Those with dome-shaped shells typically live on islands with lush, low-lying vegetation. Their dome-shaped shells and shorter necks are advantageous for grazing on the abundant vegetation found close to the ground. These tortoises don't need to stretch their necks much to reach food, so a more rounded shell provides better protection and stability.

Tortoises with saddleback shells are found on drier islands where vegetation is sparse and often elevated. Their shells are shaped like saddles, with a raised front that allows them to stretch their necks higher to reach food. This adaptation helps them access vegetation that is otherwise out of reach for dome-shaped tortoises.

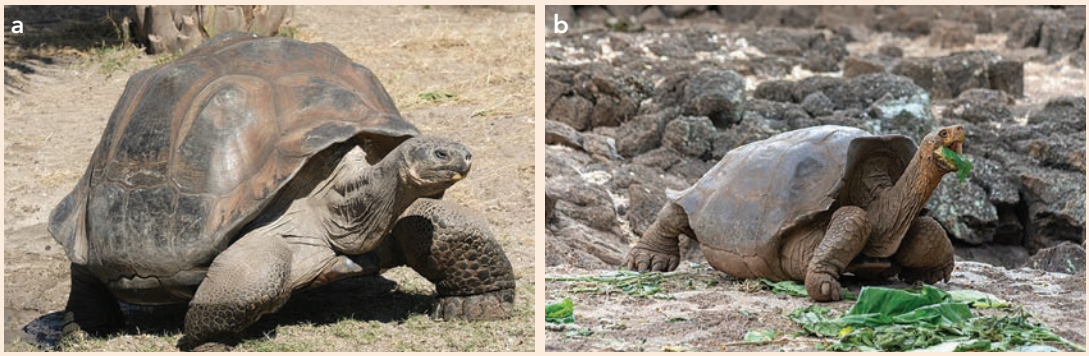

Figure 3.24 Galápagos giant tortoises: **(a)** dome-shaped shell and **(b)** saddleback shell

WIDGET
Natural selection

The process of natural selection

Natural selection occurs when an environmental factor acts on the phenotype. That is, some individuals in the population are different from others, and those differences provide an advantage or disadvantage for survival and reproduction. The following steps outline the process of evolution through natural selection.

1. Genetic variation naturally exists in the population due to processes such as sexual reproduction, genetic drift, mutations and gene flow.
2. This genetic variation means that some individuals within the population have traits better suited to their environment.
3. Individuals with favourable traits are more likely to survive and reproduce than others of their species, and thus pass on those traits to the next generation. Those favourable traits are said to be 'selected for' by environmental (or selection) pressures.
4. Over time, individuals with the favourable traits become more numerous in the population.

An example is the case of the light and dark peppered moths (*Biston betularia*) in Britain. There are two varieties within the one species – one is light coloured, the other is dark coloured – and the colour is genetically determined. Look at the moths in Figure 3.25 – the light-coloured variety of the peppered moth initially had the favourable trait (selective advantage) as it blended well with

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the lighter lichen-covered bark of the trees. This meant that a hungry bird (the selecting agent) would be more likely to see the dark-coloured moth and eat them more often. Consequently, dark-coloured moths were rare. Light-coloured moths were better adapted to survive and reproduce, so they were able to pass on their genetic information to the next generation.

Figure 3.25 There are two variations of peppered moth: light and dark coloured. Can you see both moths in each image? The picture on the left shows the moths against a light tree bark. The picture on the right shows the moths against a dark tree bark.

However, during the Industrial Revolution, pollution darkened the bark of trees. This gave the dark-coloured moths a selective advantage, as they were now better camouflaged against the trees and not as easily spotted by predators. Now the roles were reversed: light-coloured moths were at a disadvantage, and their numbers fell. The darker moth was the 'fittest' or best adapted in this new environment and so was able to survive, reproduce and pass on its genetic information to the next generation. The proportion of dark moths rose. Interestingly, cleaner air in recent decades has seen the light-coloured moths favoured once again. This example also illustrates why genetic variation enables species to survive and adapt to new circumstances.

Explore! 3.3

Challenging scientific racism

In the nineteenth and early twentieth centuries, there were many harmful misconceptions about Aboriginal and Torres Strait Islander Peoples that were considered 'scientific' at the time. These included the belief that Aboriginal and Torres Strait Islander Peoples were a less advanced race and would eventually die out. Today, such views have been thoroughly disproven and are rejected by modern science.

These racist misconceptions influenced government policies that led to the dispossession of land, restrictions on cultural practices and significant social harm. Despite this, Aboriginal and Torres Strait Islander Peoples have maintained the world's oldest continuing cultures, demonstrating remarkable resilience, rich knowledge systems and sophisticated social structures.

Use your preferred search engine to investigate how these earlier scientific misconceptions were used to support policies that negatively affected Aboriginal and Torres Strait Islander communities. What were these policies? What does this history show us about the relationship between science and society? Make sure to evaluate your sources for credibility and cultural sensitivity. Ask your teacher for help if you are unsure how to identify trustworthy information when researching Aboriginal and Torres Strait Islander Peoples.

Quick check 3.4

1. **Recall** where Charles Darwin collected his finch specimens.
2. **Create** a flow chart of the four steps involved in the process of evolution by natural selection. Then annotate your flow chart to show how each step relates to the peppered moth example.

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VIDEO
Selection pressures

Selection pressures

selection pressure a factor that affects the relative fitness or reproductive success of individuals within a population, leading to natural selection and potential changes in allele frequencies over time

Those organisms best suited to the pressures of their environment are more likely than others to survive, reproduce and pass on their genetic information to the next generation. We call these pressures **selection pressures** because they determine which variations provide individuals with better survival chances. Selection pressures refer to the factors that exert an influence on the fitness and reproductive success of individuals within a population. These pressures can be natural, such as predation, competition for resources, or climate conditions, or they can be anthropogenic, including human activities like habitat destruction or pollution. Selection pressures act as the driving forces behind natural selection, shaping the survival and reproductive outcomes of individuals based on their traits and adaptations.

Selective agents are specific factors or agents that directly cause the selection pressure. Selective agents are often associated with specific traits or features of the environment that directly impact an organism's survival or reproductive success. For example, a selective agent could be a particular predator species that preys on individuals with certain characteristics, leading to the selection for traits that enhance evasion or defence against that predator.

Selection pressures can increase or decrease the occurrence of a trait in a population. They are not static and may change with time or with changes in the environment.

Figure 3.26 Variations of adult males of the frog species *Pristimantis leopardus* may experience different levels of reproductive success due to the selective pressures exerted by predation, competition for mates, and environmental conditions, thereby driving natural selection.

Density-dependent factors	Density-independent factors
Predators	Natural disasters
Resource availability (e.g. water, shelter, nutrients)	Abiotic factors (e.g. CO_2 concentration, temperature)
Disease	
Waste accumulation	

Table 3.2 Selection pressures can be either density independent or density dependent. Density-independent pressures are typically abiotic factors (such as natural disasters or climate events that affect populations regardless of their size). Density-dependent pressures are often biotic factors (such as predation or competition for resources), which vary in impact depending on the population's size or density.

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Explore! 3.4

Selecting for sickle cell anaemia

Sickle cell anaemia is a genetic disorder in humans caused by a mutation in the haemoglobin gene, leading to abnormally shaped red blood cells that can block blood flow to parts of the body and cause severe complications such as pain, anaemia, swelling in the hands and feet, increased susceptibility to bacterial infections and stroke. However, this mutation provides a selective advantage in regions with high malaria prevalence, such as sub-Saharan Africa, Latin America and the Caribbean. The incidence of sickle cell trait ranges from 20% to 30% in areas such as the Democratic Republic of Congo, Ghana and Nigeria. In some parts of Uganda, the prevalence has been reported to be as high as 45%. Individuals with one sickle cell allele (heterozygotes) produce both normal and sickle-shaped red blood cells. These people are generally unaffected by the disease and live symptom-free but can pass the trait on to offspring. Carrying the sickle cell allele increases resistance to malaria and survival rates in heterozygous individuals.

Research the following questions.

1. How to humans become infected with malaria?
2. How does the sickle cell trait confer resistance to malaria?
3. What is the correlation between the distribution of the mutated gene and the distribution of malaria in sub-Saharan Africa?
4. Why is the sickle cell trait considered harmful in non-malarial zones but beneficial in a malarial zone?

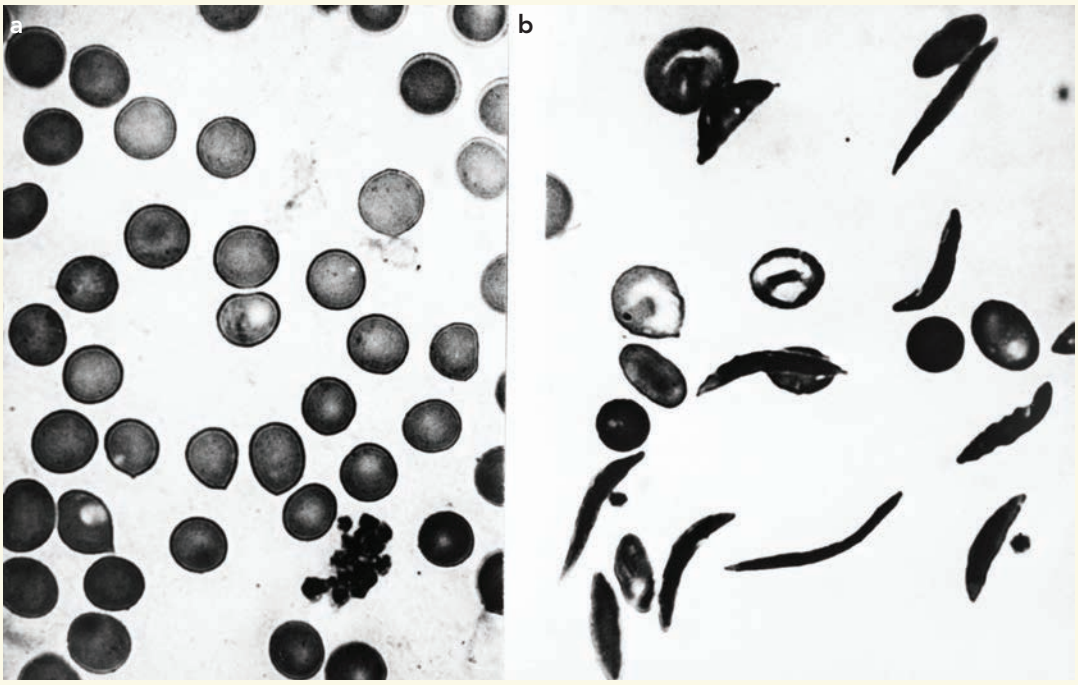

Figure 3.27 (a) Red blood cells from a healthy individual and **(b)** blood cells from an individual with sickle cell anaemia

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Try this 3.2

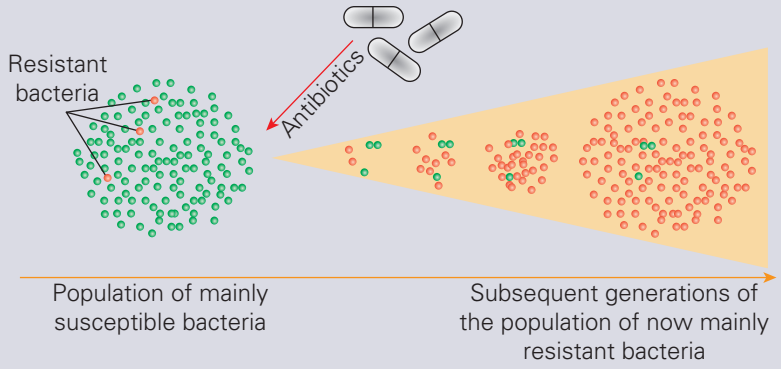
Drug-resistant bacteria and traditional medicines

Antibiotics are medicines used to prevent and treat bacterial infections. However, some bacteria have mutations that make them resistant to the effects of the drugs. The World Health Organization has identified antibiotic resistance as one of the greatest threats to human health today, potentially causing up to 10 million deaths per year by 2050 if not overcome.

Figure 3.28 *Eremophila longifolia* is one of many species of plants commonly known as 'emu bush'.

Some researchers are studying traditional bush medicines that have been used by First Nations Australians for generations as alternatives to pharmaceutical antibiotics. Plants such as tea tree (*Melaleuca alternifolia*) and emu bush (*Eremophila* species) have been found to be as effective as some established antibiotics and may provide a solution for the current resistance crisis.

Consider the following diagram carefully and then answer the questions that follow.


Resistant bacteria
Antibiotics
Population of mainly susceptible bacteria
Subsequent generations of the population of now mainly resistant bacteria

1. What variation between bacteria can you see in the original population?
2. Which variation is selected for (the fittest)? Which was selected against?
3. Which variation will contribute less to the next generation?
4. Which variation will survive in greater numbers to reproduce and pass on its genetic information to the next generation?
5. Identify the selecting agent.

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Explore! 3.5

Traditional medicines

Traditional medicines used by Aboriginal and Torres Strait Islander Peoples represent a sophisticated knowledge system developed over tens of thousands of years. These medicines, derived from careful observation, experimentation and an intimate connection to the land, have been passed down through generations and remain a vital part of many communities' healthcare practices.

Today, researchers are working alongside Aboriginal and Torres Strait Islander communities to better understand the medicinal properties of these plants and develop pharmaceuticals based on traditional knowledge. However, it is essential to recognise and respect the collaborative role of Aboriginal and Torres Strait Islander Peoples in these processes. Historically, their knowledge has been exploited, with little acknowledgement or benefit returned to the communities. Contemporary practices increasingly strive for ethical partnerships, ensuring that Traditional Owners are equal collaborators in research and benefit from any developments. For example, a dual patent was granted to Griffith University and the Jarlmadangah Burru Aboriginal Corporation for pain-relieving compounds derived from the marjala plant. This collaboration began after John Watson, a Jarlmadangah Burru elder, used the bark of the marjala plant to effectively relieve pain. His knowledge, combined with scientific inquiry, led to significant discoveries and reinforced the value of respecting and collaborating with Traditional Owners. Respecting the origins and custodians of this knowledge is critical to fostering ethical and inclusive practices in medicine and science.

Conduct some research into at least one of the plants used in the First Nations' pharmacopoeia and shown in Figure 3.29 to find out:

- what ailment it treats
- which part (or parts) of the plant is used
- how it is processed
- if there is ongoing research into their potential applications in modern medicine.

Figure 3.29 (a) Tea tree (*Melaleuca alternifolia*), **(b)** corkwood tree (*Duboisia myoporoides*), **(c)** kangaroo apple (*Solanum laciniatum*), **(d)** Moreton Bay chestnut (*Castanospermum australe*), **(e)** pale flax-lily (*Dianella longifolia*) and **(f)** crimson turkey-bush (*Eremophila latrobei*)

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Practical 3.2

Modelling natural selection

Aim

To model a beetle population to simulate natural selection and some of its consequences.

Prior understanding

Let us make the following assumptions about a beetle population:

- The original population of 30 beetles consists of 10 red, 10 yellow and 10 green.
- Each year the beetles mate once at random, and each pair produces one offspring (30 beetles produce 15 offspring, increasing the total population to 45 beetles).
- The colour of the offspring is determined by these rules:

Parent colour		Offspring colour
Parent 1	Parent 2	
Red	Red	All red
Yellow	Yellow	All yellow
Red	Yellow	All green
Green	Yellow	½ green : ½ yellow
Green	Red	½ green : ½ red
Green	Green	¼ red : ½ green : ¼ yellow

- After the beetles have produced their offspring, a predator kills ⅓ of the total population (15 beetles) each year. Therefore, the population of beetles returns to 30 at the beginning of each breeding season.
- On average, the colour ratio of beetles lost to predation is: 3 red : 2 green : 1 yellow (this ratio is reflected in the coloured sides of the dice).
- Other than the deaths caused by the predator mentioned, there will be no further deaths or migration.

Materials

- small, circular, coloured stickers (three red, two green, one yellow) that are added to the sides of a die
- 60 coloured cards of each type (20 red, 20 green and 20 yellow)

Method

1. Copy the results table into your science book.
2. To create your original population of 30 beetles, take 10 red, 10 yellow and 10 green cards.
3. Shuffle these 30 cards to model the process of random mating and deal them out into 15 pairs.
4. Using the rules from the table, determine the colour of the offspring for each of the 15 pairs.
5. Take a beetle card that represents the colour produced for each of the 15 offspring and add them to the population, creating an overall population size of 45.
6. Due to predation, 15 beetles will die and be removed each year. This will be modelled by rolling the coloured die on 15 different occasions and removing the corresponding beetle colour from the population each time. If the die lands on a particular colour of beetle that has disappeared altogether from population, roll it again.

continued …

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7. After one year of mating and predation, complete column for year 1 in the results table, showing the total number of red, green and yellow beetles that remain in the population of 30.
8. Repeat the process of mating and predation by repeating steps 3–7 for as many trials as possible (up to a maximum of 10 trials, modelling 10 years).

Results

Record the total number of red, yellow and green beetles at the end of each year in the results table.

Colour of beetle	Number of beetles after year									
	1	2	3	4	5	6	7	8	9	10
Red										
Green										
Yellow										
Total	30	30	30	30	30	30	30	30	30	30

Discussion

1. Within the population of beetles you created, identify the beetle's phenotypic trait that was observed, and its variations.
2. Explain the crucial role that variation plays in natural selection.
3. Based on your observations, did any beetle colour give a greater chance of survival than other colours in the population? Explain your answer using the data from your results table.
4. Describe how the process of natural selection relates to genetics.
5. Was there any evidence of natural selection taking place in your population of beetles? Refer to your results in your answer.
6. Did your results show any coloured beetle becoming extinct in your population over the generations?
7. a) Think of another possible ratio of a beetle predation according to colour that differs from the 3 red : 2 green : 1 yellow used in this experiment.
   b) Using the predation ratio of beetles you provided in part **a**, write a hypothesis for this experiment.
8. Another group of students obtained a beetle population of 10 red : 10 green : 10 yellow after completing the same experiment and modelling the same mating and predation rules for 10 trials. What possible explanation could be given for these results?
9. Compare the results between different student groups.
10. Can reliable conclusions and predictions be drawn from the results? Justify your response.
11. Can you identify possible limitations of this method when applied to a real-life scenario? Justify your response.
12. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining **how** each change will improve the data quality.

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Quick check 3.5

1. Variation is essential for the process of natural selection to occur.
   Explain what 'variation' means, including where it comes from in a population.
2. **Define** the term 'selection pressure' and **describe** how it contributes to natural selection.

Speciation

speciation
the process by which populations evolve to become distinct species

species
a group of organisms consisting of similar individuals who can interbreed with one another

fertile
able to reproduce

viable
able to survive

Sometimes, natural selection can lead to a new species forming, which is called **speciation**. For this to occur, there needs to be one extra step in the process of natural selection: isolation.

A **species** is often described as a group of organisms that are phenotypically and genetically similar and are capable of interbreeding with each other to produce **fertile** and **viable** offspring. However, there are at least 26 recognised ways to define a species!

For example, the offspring of a male and female horse will be a horse that is able to mate and produce offspring with another horse. However, the offspring of a female horse and a male donkey is a mule. A mule is infertile, which means it is unable to produce offspring. This is evidence that horses and donkeys are two different species: they cannot produce fertile offspring.

Hybrids are usually sterile because they either have an extra chromosome that prevents the usual meiosis process, or the chromosomes are incompatible, which means that viable gametes are not produced. However, this is not always the case. A few female hybrids have successfully bred with individuals in the original parent population.

Figure 3.30 Examples of interspecific hybrids: **(a)** mule, **(b)** 'wolphin', **(c)** liger, **(d)** zonkey

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Geographical isolation

An essential feature in speciation is isolation of populations from one another to prevent gene flow. Isolation is not required for natural selection but is necessary for speciation. Isolation may be caused by a geographical or physical barrier (for example, a large river, a desert or mountain range) or even a natural disaster like a fire, flood or volcanic eruption. The consequence is the original population is divided into two populations, not necessarily the same size.

Selection

The isolated populations may now be exposed to different selection pressures; for example, one environment may be cooler than the other. Those organisms best suited to their environment will survive to reproductive age, reproduce and pass on their genetic information to the next generation. This will increase the frequency of the trait in the population. On the cold side of the mountain, individuals with thicker fur will be selected for, while on the sunny side of the mountain, those with a thinner coat will be selected for.

Reproductive isolation

Over time, the different selection pressures on the two populations will change the genetic composition of the two populations in different ways. Eventually, enough differences may accumulate between the two populations that individuals cannot interbreed with one another to produce fertile and viable offspring. The two populations are now **reproductively isolated** and are two separate species.

reproductive isolation when members of two related populations can no longer interbreed

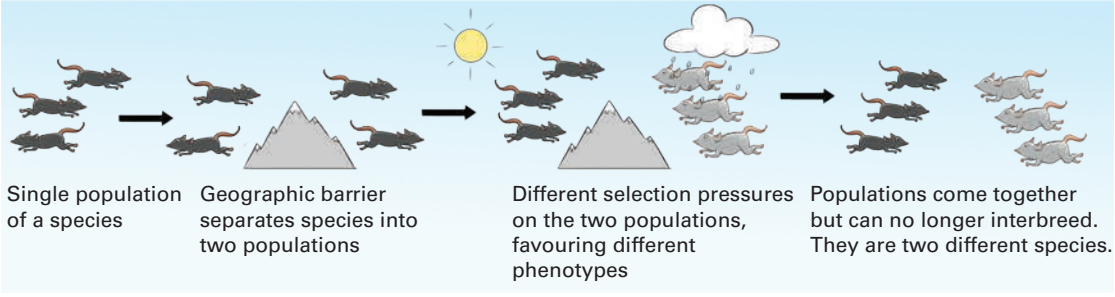
Single population of a species
Geographic barrier separates species into two populations
Different selection pressures on the two populations, favouring different phenotypes
Populations come together but can no longer interbreed. They are two different species.

Figure 3.31 Natural selection can cause speciation.

Science inquiry 3.1

Rock wallabies

Did you know there are 17 species of rock wallaby? Four of these species are found in north-west Australia and have different numbers of chromosomes. They are different species, meaning that they cannot reproduce to create fertile and viable offspring. However, scientists recently found that gene flow somehow occurs between them, meaning that despite being four different species with different numbers of chromosomes, they *can* interbreed. Scientists now know that their evolution is a lot more complex than previously thought, and the way that new species form may need to be further investigated.

Figure 3.32 Black-flanked rock wallabies

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Quick check 3.6

1. **Define** the term 'species'.
2. Speciation can occur as a consequence of natural selection with one additional step. **Recall** what must also occur and its role in speciation.
3. **Describe** how you could determine if two populations were the same species.

Try this 3.3

Speciation story time

With a classmate, take turns telling stories of speciation. You may like to use the images below as inspiration. To tell a story of speciation, use all the scientific terms you have learned that relate to natural selection and speciation. Begin by talking about the possible variation that naturally exists in your organism's population, then a possible geographical barrier that could divide and isolate the population, finishing up with the process of selection and how this leads to the creation of a new species.

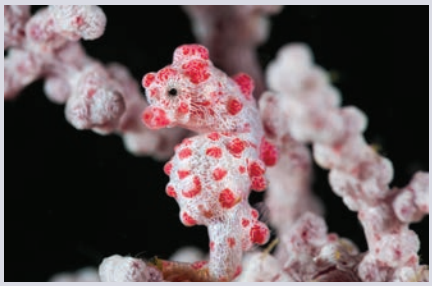

Figure 3.33 These Australian animals are perfectly suited to their environment and so can survive, reproduce and pass on their genetic information to the next generation.

VIDEO Artificial selection

Artificial selection

Artificial selection is a form of selection guided by humans rather than occurring naturally. In this process, humans choose specific traits they wish to see in future generations and selectively breed organisms that display those traits. As a result, it is human preference – not environmental pressures – that determines which individuals reproduce. For example, a farmer wants her cows to produce lots of milk, so she selectively breeds the best milk-producing cows and prevents the poorer producers from mating. Artificial selection is also called **selective breeding**, and humans have been using these techniques for thousands of years. Can you think of any other examples?

artificial selection intentional breeding of organisms with particular characteristics to produce offspring with more desirable traits

selective breeding another term for artificial selection

Artificial selection is certainly beneficial for humans, but this manipulation typically reduces biodiversity and alters the course of evolution. The outcome is often a population that is genetically very similar and has low variation. For example, there is a worldwide decline in agricultural crop diversity. A 2021 WWF report found that 75% of the food that humans eat comes from just 12 plant sources and five animal sources. Of the plants, just three crops make up 60% of the plant-derived calories in the human diet.

These crops are artificially selected for their production values, but what are the chances of the population surviving if it is exposed to a change in environment or a new disease? Reduced variation in the population may mean the crop is more susceptible to threats like these.

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Human reproductive technologies

To assist human reproduction today, we use many reproductive technologies that involve artificially selecting the genetic information that is passed to the next generation. In this way, we humans are affecting our own genetic diversity and consequently affecting our own evolution.

For example, in vitro fertilisation (IVF) involves selecting viable sperm and combining them with eggs in a test tube. After fertilisation, the healthiest embryo is selected for development and the remainder are frozen.

Medical technology lets us genetically test embryos prior to their implantation and also genetically screen babies. Decisions made on the basis of information gained by using these technologies can change the genetic composition of the human population in the next generation. Evolution takes an extremely long time, so the results of our actions will not be seen for thousands of years.

Figure 3.34 Since 1900, 76% of genetic diversity in agricultural crops has been lost, but there is renewed interest in heirloom or heritage crops. Heritage apples are those that were grown before World War II. Some still remain, but many have been lost after commercial orchards that grow mass-produced apples such as pink lady, Granny Smith and gala became more popular. New varieties of apples are constantly being developed to bring novelty to the apple industry. One example is the yello, a cross between a golden delicious apple and a heritage apple from Japan called senshu.

Figure 3.35 Artificial selection in action: each of these organisms was selectively bred for particular characteristics.

Did you know? 3.4

Broccoli and kale are the same

Did you know that broccoli, kale, cabbage, brussels sprouts, cauliflower and gai lan are just some of the variations of the plant species *Brassica oleracea*? Each variation is called a 'cultivar', which is a plant variety produced by selective breeding.

Figure 3.36 Some of the many varieties of *Brassica oleracea*

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Explore! 3.6

Dog breeds

All domestic dogs belong to one species, *Canis familiaris*, so how can they appear so different? Go online to research the following topics.

1. Choose one dog breed and identify its unique characteristics.
2. Critique some of the ethical considerations involved in breeding a dog for a particular characteristic that may be detrimental for their health. For example, the cocker spaniel's long floppy ears make it particularly susceptible to ear infections. The pug's wrinkled face is susceptible to infections resulting from dead skin cells and moisture being trapped in the folds of skin.

Figure 3.37 Despite their differences, domestic dogs are all the same species!

Gene technologies

Desirable traits can also be acquired using gene technology, rather than relying on selective breeding. Gene technology lets us transfer genes from one individual or species to another. Gene therapy allows faulty genes found in an organism to be replaced by the normally functioning gene. Genetically modified organisms (GMOs) are produced when an organism has its DNA altered or modified using genetic engineering.

Try this 3.4

Genetic technologies

Choose a genetic technology (for example, CRISPR, gene therapy, DNA sequencing) and identify a specific purpose for its use (for example, medical treatment, agricultural improvements, forensic analysis). Conduct research on your chosen genetic technology, including its development, mechanism of action, applications, benefits and potential ethical concerns.

Present your findings in one of the following formats.

- Journal article: Write a detailed article with sections including an abstract, introduction, methodology, results, discussion and conclusion. Include references to your sources.
- Video news piece: Create a three-to-five-minute video presenting the technology, its purpose and your findings. Use visuals, interviews and clear narration to engage the audience.
- Brochure: Design an informative brochure with sections covering the key aspects of the technology. Use images, graphs and bullet points for clarity and visual appeal.

Consider how gene therapy could change the biodiversity of the human population. Would there be more or less variation? And what would this mean for the process of evolution? What about GMOs? Genetically engineered cotton crops (*Bacillus thuringiensis* cotton, or Bt cotton for short), were created to produce an insecticide to combat bollworm. GM cotton was first grown in Australia in 1996, and now, over 99.5% of cotton grown in the country is genetically modified. What effects could GMOs have on biodiversity and evolution? What ethical considerations would need to be made?

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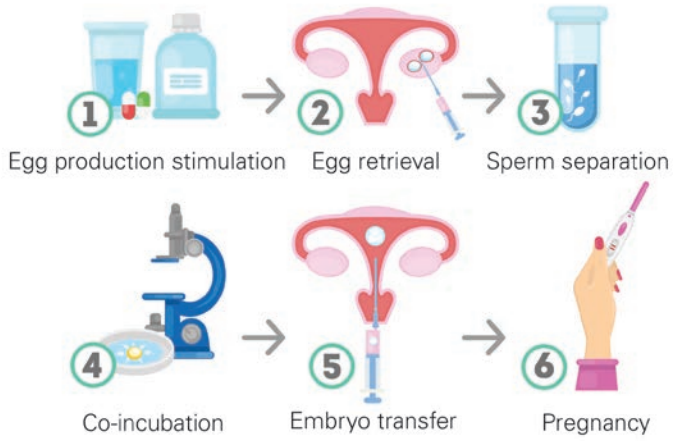

Figure 3.38 The process of IVF artificially selects the eggs, sperm and embryos that have the best chance of survival.

Figure 3.39 Worldwide, bollworm causes millions of dollars worth of damage a year to crops such as cotton and vegetables.

Explore! 3.7

What will humans look like in 10 000 years?

Some scientists have argued that civilisation has ended natural selection in humans. To a large degree, the selection pressures of the past (such as predation) no longer affect us in the same way. Humans modify their surroundings to survive in a wide range of environmental conditions, and vaccines and antibiotics help us to address disease.

However, there have been evolutionary changes since the earliest civilisations. As diets changed to include grains and dairy, genes that coded for enzymes to digest starch and lactose were selected for. People now live in densely populated regions, which could allow the rapid spread of disease, but they also have mutations that code for disease resistance.

Today, evolution has become less about survival and more about reproduction. Some scientists have suggested that this greater focus on reproductive success might increase selection for attractiveness. And humans might also become more uniform in appearance as travel leads to mixing of populations, and easy access to worldwide media may create a set standard of beauty.

Scientists have suggested that the following changes may take place in humans over the next 10 000 years. Complete some research and discuss why future humans may have:

- longer lifespans
- taller stature
- lighter, less-dense skeletons
- reduced muscle, especially in the upper body
- smaller jaws
- fewer wisdom teeth
- smaller brains
- less aggressive behaviour.

Quick check 3.7

1. **Define** the term 'artificial selection' and provide an example.
2. **Contrast** natural selection and artificial selection.
3. **Discuss** whether artificial selection increases or decreases variation and therefore biodiversity.
4. **Explain** how reproductive technologies can affect human biodiversity.

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Go online to access the interactive section review and more!

Section 3.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 3.2 questions

Remembering

1. **Recall** the key processes involved in natural selection.
2. **Identify** geographical barriers that could divide a bird population, an eel population and a mammal population.
3. **State** the different sources of variation in an individual and in a population.
4. **Identify** three examples of abiotic selection pressures and three examples of biotic selection pressures.
5. **Name** some different ways that technology can affect the biodiversity of the human population.

Understanding

6. **Describe** what is meant by the term 'selective advantage'.
7. **Summarise** the three processes in speciation.
8. **Explain** why variation is necessary for natural selection to occur.
9. **Explain** why isolation is necessary for speciation to occur.

Applying

10. Tomato breeders have created the sweetest and juiciest tomato ever. **Predict** how they would have done this, given that they started with a not-so-sweet and not-so-juicy crop of tomatoes.

Analysing

11. **Distinguish** between artificial and natural selection, providing examples for each.
12. The Galápagos finches share similar features but are recognised as distinct species. **Propose** a test that could be used to identify if two similar kinds of finch are different species or subspecies of the one species.

Evaluating

13. **Determine** how speciation, biodiversity and evolution are linked.
14. **Decide** if humans are evolving by natural selection.
15. **Predict** what will happen if a population of a particular species has low genetic variation and there are changes in the environment in which its members live.

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3.3 Evidence for evolution

Learning goals

At the end of this section, I will be able to:

1. Describe the evidence for evolution.
2. Describe how a fossil forms.
3. Describe that radiometric dating of fossils relies on nuclear decay processes.

WORKSHEET
Evidence for evolution

Evolutionary theory is supported by a multitude of evidence and findings from observations and experiments, including the sources in Table 3.3.

Field of science	Evidence
Palaeontology	The study of fossils, including their identification and interpretation, enabling the identification and interpretation of ancient organisms, which contributes to our understanding of past life forms and evolutionary history
Comparative anatomy	The study of the structure of specific organs and limbs of different organisms, providing insights into their functional adaptations and evolutionary relationships
Embryology	The study of the development of the embryo in different organisms, providing information about shared developmental processes and evolutionary patterns
Molecular phylogeny	The ability to sequence DNA to indicate the degree of relatedness between organisms, aiding in the construction of evolutionary trees and understanding evolutionary relationships
Biochemistry	Similarities and differences in the biochemical make-up of organisms that can help distinguish differences and similarities
Biogeography	The study of the geographic distribution of organisms, which can help ascertain the origins, dispersal and adaptation of species in different regions

Table 3.3 Sources of scientific evidence for the theory of evolution

VIDEO
Paleontology

Palaeontology

The term **fossil** refers to any parts of, or impressions made by, a plant or animal that is preserved following death. Normally, an organism decomposes after it dies, and after a time, no trace of it remains. On rare occasions, evidence of the organism is preserved in the form of a fossil. Fossils may be the hard parts of an organism, like its bones and teeth (called **direct** evidence), or evidence of an organism's presence, like footprints, burrows and faeces (called **indirect** evidence or **trace fossils**.). The process of forming a fossil is called **fossilisation**. However, because fossilisation is rare, and certain conditions are also required in order for fossilisation to take place, and organisms with hard parts are more likely to form fossils, there are gaps in our **fossil record**. Also, we cannot dig everywhere looking for fossils, so many go undiscovered.

fossil
the shape or impression of a bone, a shell or a once-living organism that has been preserved for a very long period of time

direct (evidence)
evidence that supports an assertion without intervening inferences

indirect (evidence)
evidence that requires inferences to be made

trace fossil
a trace of an animal, such as a footprint or imprint, that has become fossilised

fossilisation
the process of forming a fossil

fossil record
the record of past life and evolution inferred from fossils

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Fossilisation

Fossils are formed in many ways, but they are most likely to be found in sedimentary rock. When an organism dies, soft tissues normally decompose, leaving only the hard parts behind. The organism gets buried under sediment, volcanic ash or lava. Over a period of time, minerals can fill up empty spaces or replace material, eventually changing to rock.

Figure 3.40 Many opalised fossils have been found on the opal fields of Coober Pedy, South Australia. This phenomenon occurs when opal, instead of the usual minerals found in groundwater, replaces the skeletal material. The photos show a drawing of **(a)** an extinct, squid-like belemnite, **(b)** a belemnite fossil found in shale and **(c)** an opalised belemnite found in Coober Pedy.

Other ways in which fossils can be formed are presented in Table 3.4.

Method of fossil formation	Description
Impression	The organism's remains are washed away, but an empty space is left in the shape of the organism. If it remains empty, it is a mould. If it fills with minerals, then it is a cast. If it fills with lava, then it forms a rock in the shape of the mould. **Figure 3.41** An impression fossil of a pterosaur
Amber	Organisms become trapped in tree resin that then hardens. **Figure 3.42** A 100-million-year-old spider attacking its prey

Table 3.4 Methods of fossilisation

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Method of fossil formation	Description
Trace fossils	Trace fossils, such as footprints, burrows or faeces, give some insight into an organism's behaviour, how it lived and how it interacted with the environment. **Figure 3.43** Dinosaur footprints at Gantheaume Point, Broome. Trace fossils can provide important information relating to the size and walking or running posture of an extinct species.
Soft tissue	It is extremely rare for soft tissues to survive the pressure, heat and chemical changes needed for fossilisation to occur. But nowadays, scientists are increasingly reporting finding fossilised skin and even brain material preserved along with bones. **Figure 3.44** In 2018, researchers found what they believe are fossilised lungs preserved inside a 120-million-year-old bird. Scientists have previously found four fossils of this ancient bird, *Archaeorhynchus spathula*, but never with plumage or suspected lungs.

Table 3.4 *(continued)*

Fossilisation requires the following conditions:

- Burial is rapid. Organisms must be buried quickly in oxygen-poor sediments. Usually this happens when organisms die in seas, lakes, floods or mud slides. Organisms can also be preserved in ice or amber or buried under ash from volcanic eruptions (lava will usually incinerate any remains).
- Decomposition is prevented. Bacteria, which normally cause the decay of organisms, must be reduced or absent. For example, many bacteria that cause decomposition will die in the absence of oxygen or water, or in conditions of high acidity or extreme cold. Soft tissue and organs break down chemically, so they do not usually get fossilised even in the absence of bacteria.
- Remains lie undisturbed. Predators and scavengers must not dig up the remains, and if the remains are in water, they must not be subject to wave action and currents.

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Figure 3.45 Hamelin Pool Marine Nature Reserve is one of only two places in the world where living marine stromatolites can be observed. These ancient structures, formed by cyanobacteria in hypersaline waters, offer a direct link to early Earth conditions, resembling microbial life from billions of years ago.

Figure 3.46 A fossilised skull of *Eastmanosteus calliaspis*, a fish species collected from what was once a lagoon behind a barrier reef.

Quick check 3.8

1. **State** two sources of evidence for evolution.
2. **Recall** some of the information you can find out from fossils that helps explain evolution.
3. **Explain** why it is rare to find fossils.
4. **Summarise** the conditions required for fossilisation.
5. **Describe** what is meant by a 'trace' fossil.

Did you know? 3.5

Living fossils

Charles Darwin coined the phrase 'living fossils' and, despite not being a scientific term, it has remained in use. It describes modern species of plants and animals that are almost identical to species that lived in ancient geological ages. This means they have survived mass extinctions, ice ages and comets hitting Earth! Examples include the Wollemi pine, the Australian lungfish, mountain shrimp and the Australian ghost shark.

Figure 3.47 The Australian lungfish (*Neoceratodus forsteri*) is considered a 'living fossil' as it was prevalent in the Devonian period, some 400 million years ago!

relative dating determining the order of past events without the specific age

stratigraphy the branch of geology studying rock layers

Dating fossils: Relative dating

Until last century, **relative dating** was the only method available for dating fossils. As the term suggests, relative dating techniques only work out how the age of a fossil compares to the ages of other fossils. For example, it can tell you that fossil X is older than fossil Y, but it cannot tell you the actual numerical age of the fossil. Relative dating is used to order the layers of rocks and geological events into a time sequence. The study of the order of the layers of rock (strata) is called **stratigraphy**.

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Try this 3.5

Stratigraphy

Where the sediments in which fossils are found have not been disturbed by later events, they nearly always show an age sequence, with the oldest fossils deepest under the ground and the youngest at the top. Often these fossil sequences let us see the change in a species over time. This highlights how the fossil record is valuable for collecting evidence of evolution. For example, fossils have provided evidence for the evolution of modern horses from the ancient four-toed mammal, and the discovery of *Archaeopteryx* gave us evidence for the link between reptiles and birds. The fossil record also tells us more about organisms that are now extinct and what Earth was like when particular species existed.

The diagrams in Figure 3.48 represent the strata (rock layers) found at two different locations (1 and 2). Each layer has a letter associated with it, and you can see the different fossils found in each layer. Knowing that the youngest layers are on the top and the oldest down below, work out the relative age of all the layers in both locations from oldest to youngest. Then list the clues you used to work this out.

For example, layer G is younger than layer B, but older than layer A.

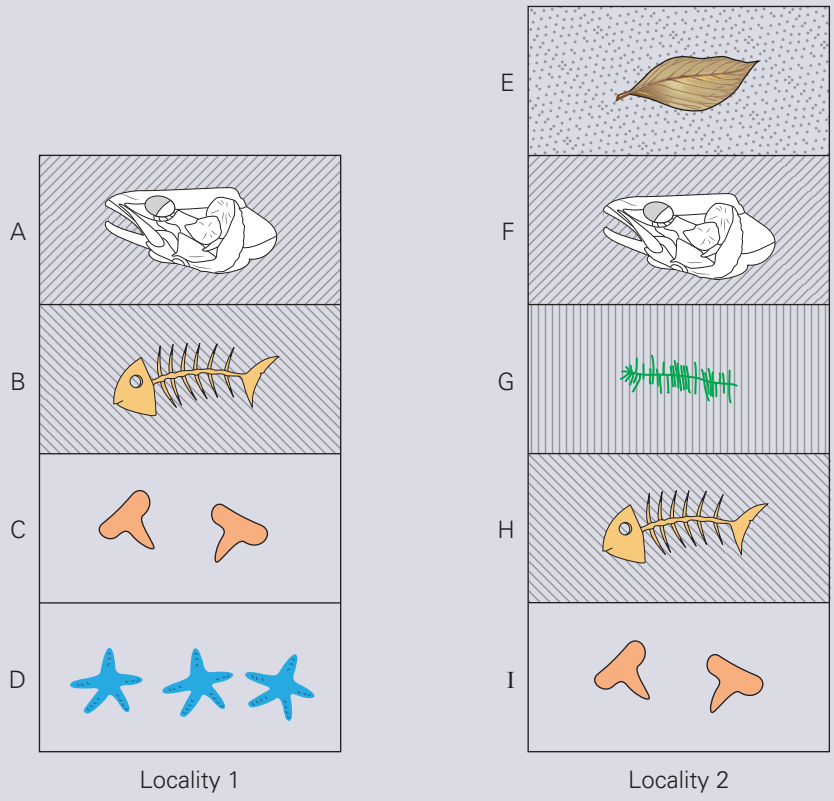

Figure 3.48 Relative dating: the different strata and their relative positions at locations 1 and 2 help us date the fossils in each layer relative to other fossils.

Fossils are important for working out the relative ages of sedimentary rocks too. Similar fossils in different rocks, even if a great distance apart, suggest the rocks are the same age. This matching process is called correlation, and it has been important in constructing geological timescales. Throughout the history of life, different organisms have appeared, flourished and become extinct. Some of these organisms became fossilised in sedimentary rocks. The geological study of their patterns of appearance and disappearance over time is called **biostratigraphy**.

biostratigraphy a branch of stratigraphy focused on dating rock layers using the fossils found in them

index fossil a fossil used as the basis for dating the strata it occupied

To help identify matching strata, and to compare strata in different locations, indicator or **index fossils** can be used. An index fossil is a fossil of known age found in a particular type of sedimentary rock layer. It can be used to indicate the age of any deposit in which it is found, at any locality. For example, trilobites are good index fossils as they were very common at the time they existed (between 488 and 225 million years ago), easy to recognise, well preserved because of their hard exoskeleton and they evolved rapidly, which means there were different species present at different times. So if a fossil was found underneath this layer, then it could be deduced that it is older than 488 million years.

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Did you know? 3.6

Two legs better than four?

The fossil record shows that kangaroo ancestors were quadrupedal (walking on four legs) and had teeth adapted to eating woody vegetation. These adaptations were advantageous in forested habitats, but as the environment started to dry out, giving way to open grassland, the selection pressures of the environment were very different. Over millions of years, what we now know as kangaroos became bipedal and their teeth evolved to be able to graze on grass.

Figure 3.49 At low speeds, bipedal hopping is energy inefficient for a kangaroo. It only becomes useful at high speeds. Since their environment changed millions of years ago, hopping has provided a useful adaptation to evade predators in wide open grasslands.

Dating fossils: Absolute dating

absolute dating determining the actual age of a material

radioisotope a radioactive isotope of a chemical element with an unstable nucleus that emits excess energy (radiation)

half-life the length of time needed for the radioactivity of a radioactive substance to be reduced by half

Absolute dating gives a precise age (within certain error margins) for a fossil or, more commonly, for the rock or soil in which a fossil is found. Absolute dating uses radiometric techniques, which means looking at the level of radioactivity detected in rocks containing certain naturally occurring radioactive isotopes (**radioisotopes**). These isotopes occur in living things and have a known rate of radioactive decay. By measuring the amount of radioactive isotope left in a sample, we can work out for how long the organism has been dead. The time in which half of the sample of the radioactive isotope (parent) has decayed to a more stable form (daughter) is known as its **half-life** and is unique to each isotope. Knowing this helps us determine the best isotope to use to work out the absolute age of a fossil. The longer the half-life of the isotope used, the older the fossil or rock that can be dated.

Figure 3.50 Fossil of a trilobite, *Albertella helena*

Radioactive isotopes (parent to daughter)	Half-life (years)	Estimated age range of fossils they can date
Carbon-14 to nitrogen-14	5730	Up to 55000 years ago
Uranium-235 to lead-207	710000000	1 million to 1 billion years ago
Potassium-40 to argon-40	1300000000	500000 years and older

Table 3.5 Each radioactive isotope has a different half-life. The longer the half-life, the older the fossil or rock that can be dated.

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Practical 3.3

Modelling half-lives

Be careful
Do not consume food items.

Materials

- M&Ms or counters with one side marked × 100
- plastic container with lid
- plastic tray
- graph paper
- gloves

Method

1. Copy the results table into your science book.
2. Predict the number of M&Ms that will 'decay' into daughter isotopes each time trial. Place all 100 M&Ms parent isotopes on your plastic tray with the 'm' side up.
3. Record your original number of parent isotopes in your results table for time 0.

4. Place all the isotopes in the plastic container and shake for 10 seconds.
5. Pour your isotopes back onto the plastic tray.
6. With your gloves on, remove all the stable daughter isotopes (m side down) from the tray and set them aside.
7. Count the remaining M&Ms (parent isotopes), which will be a percentage of the original number since that was 100, and record this in your results table for time 1.
8. Repeat steps 4–7 another eight times, ensuring that you only place parent isotopes back in the container each time.

Results

1. Collate the class results on the board and calculate means for each time.
2. Calculate the percentage of undecayed parent isotopes for each time period.
3. Draw a graph of the time (*x*-axis) versus percentage undecayed parent isotopes (*y*-axis) using the class results.

Time	Number of removed daughter isotopes	Number of remaining parent isotopes	Percentage undecayed parent isotopes $\frac{\text{Number of remaining parent isotopes}}{\text{Starting number of parent isotopes}} \times 100$	Class mean percentage undecayed parent isotopes
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				

4. Calculate the half-life of your isotope by using your graph to identify the time in which half of the parent isotopes had decayed into daughter isotopes.

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Did you know? 3.7

Did First Nations Australians and Australian megafauna coexist?

Zygomaturus trilobus was a large wombat-like marsupial approximately the size of a bull. Dating using uranium–thorium shows that a fossil specimen of *Zygomaturus* died 33 000 years ago. We know that First Nations Australians arrived in the same area at least 50 000 years ago, so the uranium–thorium dating shows that people and megafauna coexisted for at least 17 000 years. The coexistence of First Nations Australians and Australian megafauna is further supported by paintings in Arnhem Land rock shelters of species such as *Genyornis newtoni* and *Palorchestes parvus*.

Figure 3.51 This rock painting of the megafauna herbivore in the genus *Palorchestes* displays two prominent tufts of chest hair and is accompanied by a smaller (perhaps younger) version of the same animal.

Science inquiry 3.2

The latest fossil finds

In 2022, an international team of palaeontologists identified the world's oldest meal in a 550-million-year-old fossil. Analysing the fossilised remains of a slug-like Ediacarian called *Kimberella* showed that it had a mouth and a gut and ate algae and bacteria from the ocean floor. The organism was advanced for the time period, as most other species did not have a gut that went through their entire body.

Figure 3.52 New fossils are providing key insights into the evolution of life on Earth.

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Quick check 3.9

1. **Describe** relative dating.
2. **Define** the terms 'stratigraphy' and 'index fossil'.
3. **Describe** absolute dating.
4. **Name** one isotope that could be used to accurately measure the absolute age of a fossil.

Comparative anatomy

Genetic variation can produce a huge diversity of forms among closely related organisms. But some animals display physical likeness despite not being closely related at all. Think about a bird and a bat, a dolphin and a shark, a sugar glider and a flying squirrel. The members of each pair, despite not being closely related, share some obvious structural characteristics. For example, sugar gliders and flying squirrels look alike, sharing similar characteristics such as size, big eyes and a white belly. Their most striking similarity is that they both have thin, loose skin between their limbs, which keeps them stable when stretched while they glide (see Figure 3.53).

However, sugar gliders (native to Australia) and flying squirrels (native to Asia, Central and North America, and Europe) also have many differences. Sugar gliders are marsupials, so they have a pouch to protect their young, whereas flying squirrels are placental mammals, having larger babies and no pouch.

By studying their genes and other traits, biologists discovered that sugar gliders and flying squirrels are not very closely related at all. So why do they share some common physical characteristics?

The characteristic 'wings', which are flaps of skin, are known as **analogous structures**. These are structures that have a similar function but have evolved independently — a phenomenon known as **convergent evolution**. The two organisms have evolved from different ancestors but in similar environments, so the same selection pressures have caused the same feature to be selected for. The streamlined shapes of sharks (fish), penguins (birds) and dolphins (mammals) are examples of analogous structures (see Figure 3.54). Although they belong to different groups and do not share a recent common ancestor, they have evolved similar body shapes adapted for efficient swimming. Sharks have fins, dolphins have flippers and penguins use their wings to propel themselves through water. These similarities have arisen because all three have faced similar selection pressures in aquatic environments.

analogous structures structures that have a similar function but evolved separately

convergent evolution the process by which unrelated species independently evolve similar traits due to similar environmental pressures

Figure 3.53 (a) A sugar glider and **(b)** a flying squirrel have many common characteristics, but they are not closely related.

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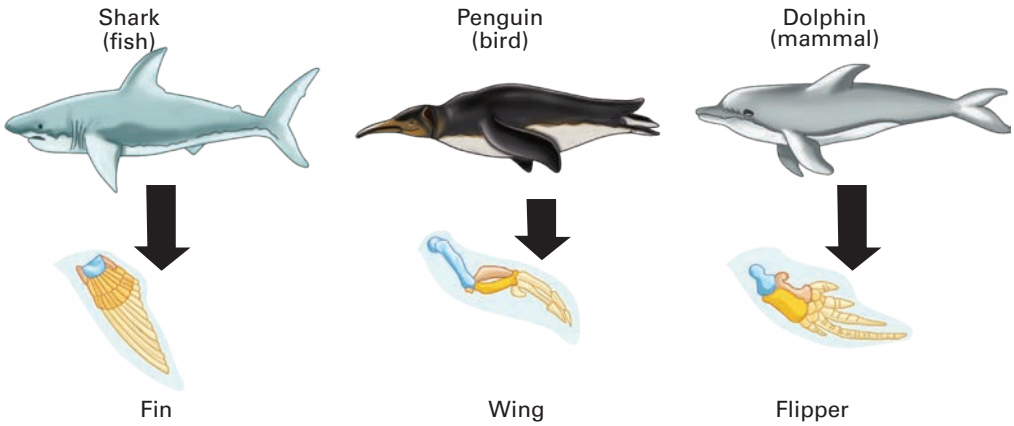

Figure 3.54 The shark, penguin and dolphin have analogous structures, that is, structures with the same function. These arose because they live in similar environments and face similar selection pressures.

homologous structure a similar physical feature in organisms that have evolved from the same common ancestor

divergent evolution when closely related species evolve different traits, adapting to different environments or selection pressures from a common ancestral form

Homologous structures are structures that organisms inherit from a common ancestor. 'Homo' comes from the Greek word *homos* meaning 'same'; hence, they inherited the same general body plan from the same ancestor. This process, known as **divergent evolution**, means these structures have a common evolutionary history. Homologous structures have similar underlying anatomy but have evolved in different ways over time due to different selection pressures. An example of a homologous structure is the pentadactyl limb, the five-digit limb typical of tetrapod (four-limbed) vertebrates (that is, amphibians, reptiles, birds and mammals). The limbs of different species show basic similarities in the bones present and how they are arranged, even though the limbs may serve different functions (see Figure 3.55).

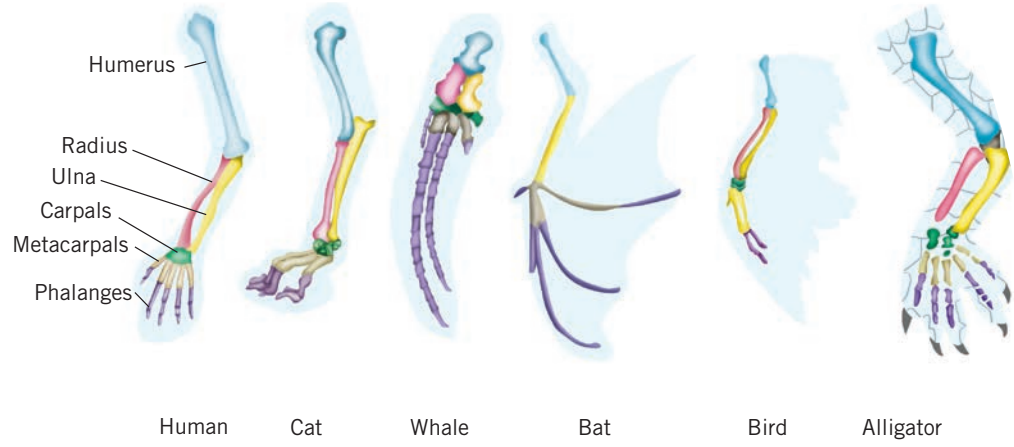

Figure 3.55 The limbs of different tetrapod vertebrates have a common structure and are called homologous, despite having different functions, such as grasping, swimming or flying.

The different limbs are the same bones arranged for different uses. If homologous structures are found in different organisms, that suggests they had a relatively recent common ancestor, which helps to explain their evolutionary path.

Figure 3.56 (a) The hair of mammals, **(b)** feathers of birds and **(c)** scales of reptiles are structures that share a common ancestry in reptilian scales; they have been inherited and modified over time. The fibres in each are composed of keratin complexes.

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Quick check 3.10

1. **Describe** analogous structures, providing an appropriate example.
2. **Describe** homologous structures, providing an appropriate example.

Practical 3.4

Dissection of a chicken wing

Be careful
Take care when using scissors and probes. Clean the benches and wash your hands before leaving the laboratory.

Aim

To compare the structure of a chicken wing to the structure of a human arm.

Materials

- fresh chicken wing
- dissecting board
- dissecting scissors
- probe
- disposable gloves
- human skeleton model

Method

Part 1: Examining the chicken wing

1. Hold the chicken wing at the shoulder and the tip and then stretch out the wing. Identify where the joints are and in which direction they bend.
2. Use your fingers to feel the bones and muscles under the skin.
3. Using dissecting scissors, carefully remove the skin from the chicken wing, taking care not to cut the muscles, ligaments and tendons.
4. Identify the muscles of the wing and see if you can work out how each one is attached to the bones of the wing.
5. Look for the tendon, which is white and tough and attaches the muscle to the bone.
6. Try squeezing the muscle in the wings and observe what happens to the bones. You may notice there are two muscles which can flex or extend the wing.
7. Look at the surface of each bone where it forms a joint. It should appear white, shiny and slippery – this is called cartilage. Can you find the cartilage at the joint between the humerus and the radius and ulna?

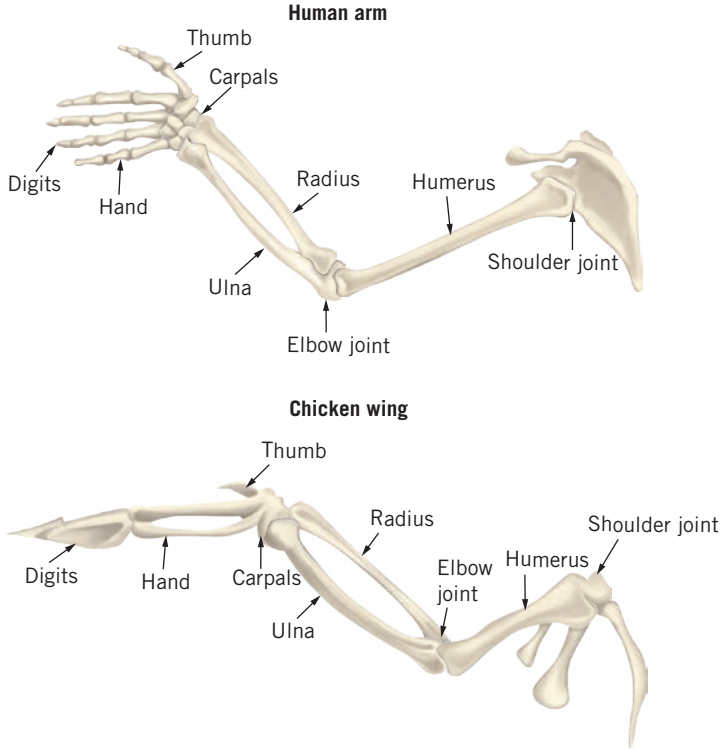

Figure 3.57 The bones of a human arm and a chicken wing

continued …

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Part 2: Examining your arm

1. Identify the humerus, ulna and radius in your arm. What other features of the chicken wing and your arm are similar?
2. Bend your arm at the elbow and hold it tight. Notice that your bicep muscle shortens. Now, extend your arm and feel your bicep lengthen.
3. Now, look at your hand and identify where the muscles are that move your fingers. You may need to press on your wrist or forearm to figure this out.
4. With a partner, raise and lower a textbook by bending your arm at the elbow. Which muscles were acting as you raised and lowered the textbook?

Results

Take a photo of the finished dissection of the chicken wing.

Discussion

1. Compare the structure of a chicken wing with a human arm.
2. Define the term 'analogous structures' and explain what they can tell us about the evolution of a species.
3. Define the term 'homologous structures' and explain what they can tell us about the evolution of a species.
4. Would the chicken bones and human bones be considered homologous or analogous structures? Discuss.

evolutionary tree a diagram used to represent evolutionary relationships between organisms

Scientists can construct **evolutionary trees** using fossil evidence and radiometric dating to estimate when different groups of species diverged from a common ancestor. Evolutionary trees can be constructed when scientists have studied the anatomy of different species to determine which ones have homologous structures. Only homologous traits are evidence of a shared ancestry. An example of an evolutionary tree is shown in Figure 3.58.

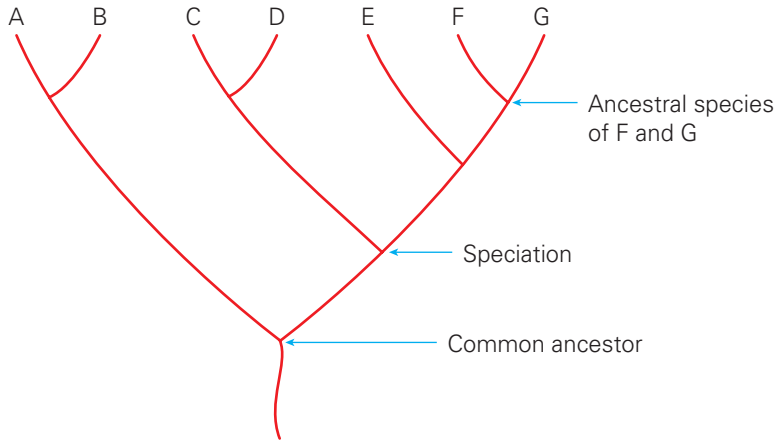

Figure 3.58 An example evolutionary tree

For example, humans, chimpanzees and gorillas all have thumbs that are very similar anatomically and are considered to be homologous (see Figure 3.59). The giant panda also has a thumb, but it has been found to be analogous to these primate thumbs – it serves the same function but is structurally formed by different bones, so it evolved separately. This suggests that humans, chimpanzees and gorillas are much more closely related to one another than any of them is related to giant pandas.

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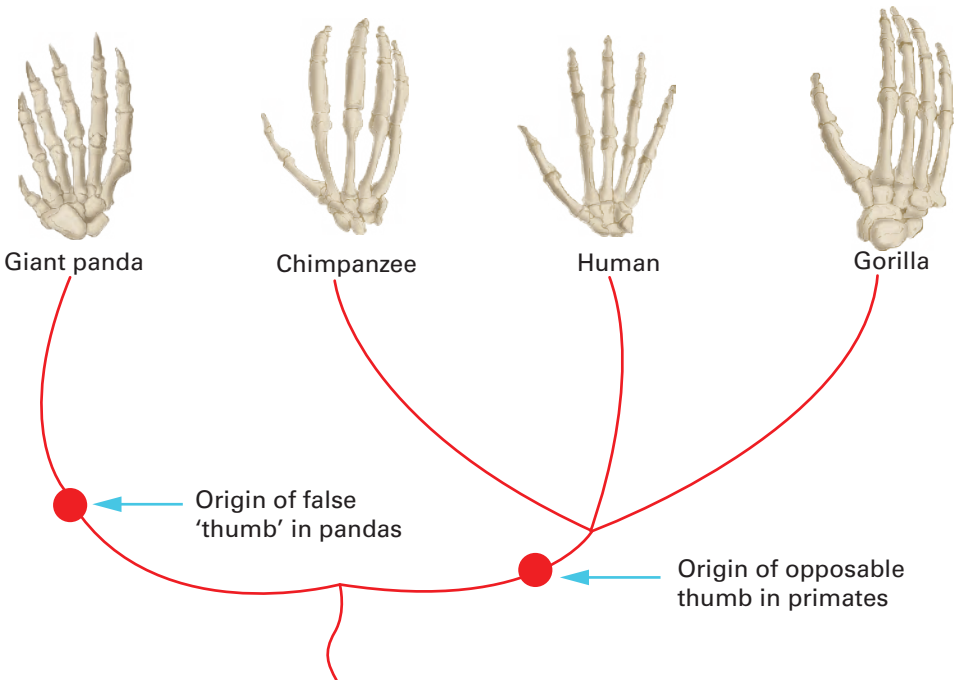

Figure 3.59 An evolutionary tree showing how the homologous opposable thumbs of humans, chimpanzees and gorillas mean that these species have a recent common ancestor

Comparative embryology

The embryos of vertebrate animals look very similar in the early stages, which suggests that they inherited some of the genetic information that contributes to embryo development from a common ancestor. For example, a very early stage human embryo has gill slits, a tail and a simple heart, similar to that of a fish. At later stages, the human embryo develops body proportions similar to the embryos of reptiles and then apes.

Comparative embryology also finds evidence for evolution in the circulatory system of fish and mammals. Adult fish and mammals have quite different circulatory systems. However, during embryonic development you can clearly see that the circulatory systems are based on the same pattern. This suggests that the genetic information responsible for the development of the fish and mammalian circulatory systems has been inherited from a common ancestor.

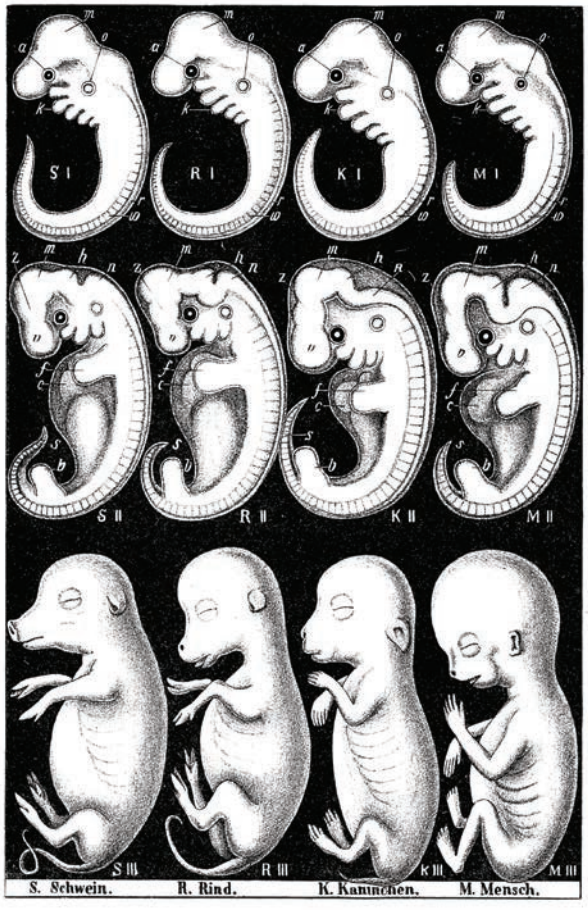

Figure 3.60 Comparative embryology drawings of embryos at three stages from (left to right): a pig, cow, rabbit and human

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Quick check 3.11

1. **Describe** an evolutionary tree.
2. **Explain** how embryology provides evidence for evolution.

Molecular biology

Substances that are found in most or all living things are very useful in the investigation of evolutionary relationships. For example, all living things contain DNA, so it is commonly used to compare organisms. This is what the study of molecular biology is all about – investigating DNA, its code and the proteins it codes for. Molecular biology lets evolutionary scientists:

- trace ancestors of species
- estimate how long ago one species diverged into two
- discover how closely related two species are.

DNA analysis

DNA hybridisation a technique that measures genetic similarity between two organisms

DNA hybridisation is one type of technique used to compare the DNA sequences of two species to find out how closely related they are. First, as shown in Figure 3.61, the DNA from each organism is extracted and heated so it forms two single strands. When the single strands from the two organisms are mixed together and allowed to cool, complementary nitrogenous bases will bind together (hybridise). The degree to which the single strands form a stable double-stranded DNA molecule is an indication of the relatedness of the species. For example, if there is a lot of hybridisation, there must be a lot of complementary bases, which means the organisms are similar and, therefore, have a recent common ancestor.

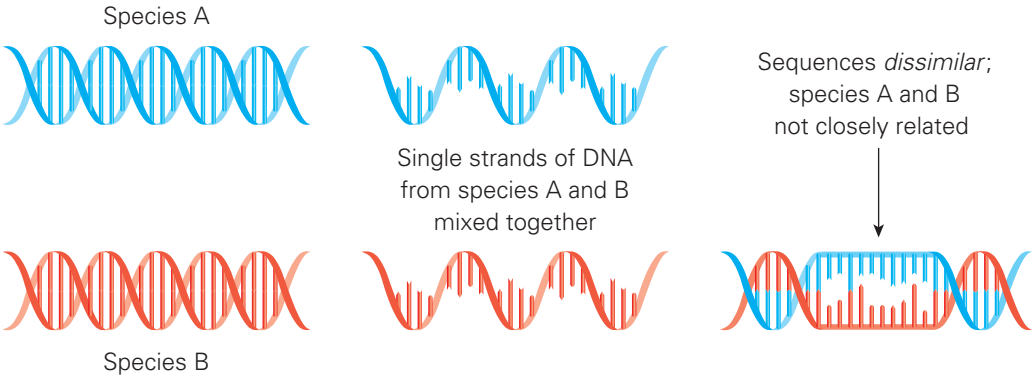
Species A
Single strands of DNA from species A and B mixed together
Sequences *dissimilar*; species A and B not closely related
Species B

Figure 3.61 The process of DNA hybridisation allows scientists to determine the relatedness of two organisms by comparing their DNA.

Protein analysis

As we know, proteins are made up of building blocks called amino acids. Scientists can analyse the differences in the amino acid sequences, knowing that this relates to how similar proteins are in the different organisms. The number of different amino acid sequences in the proteins of different species is an indicator of the number of mutations and hence the degree of separation of species. In other words, a large difference in amino acid sequences between two organisms means they had a distant common ancestor, while a small difference in amino acid sequences means they had a recent common ancestor. This is because they had less time for mutations to accumulate. The cytochrome c protein is often studied as it is involved in cellular respiration and is found in most eukaryotic organisms. Table 3.6 shows the differences in the amino acid sequence for cytochrome c between humans and other organisms. Notice how the monkey has the lowest number of differences, suggesting that monkeys are more closely related to humans.

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Note that it is also possible to predict amino acid sequences from the DNA code, and the latter also tells you about the relationship between organisms.

Organism	Number of differences in the amino acid sequence for cytochrome c, compared to humans
Horse	12
Chicken	13
Dog	11
Moth	31
Tuna	21
Monkey	1

Table 3.6 The differences in the amino acid sequence for cytochrome c between humans and other organisms

Did you know? 3.8

Molecular clocks

The molecular clock concept says that mutations accumulate in biomolecules at a roughly constant rate because they occur by chance. We can use this mutation rate to deduce the time when life forms diverged. The biomolecular data that is normally used for calculations are DNA nucleotide sequences, including those found in mitochondrial DNA (mtDNA).

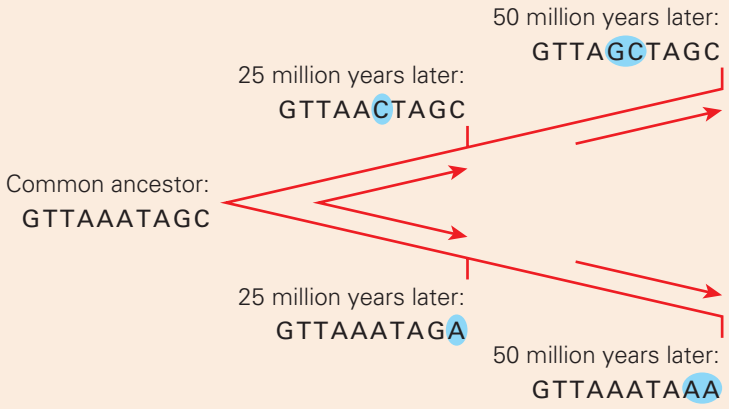

Figure 3.62 In the same way that a clock tells the time, a molecular clock allows scientists to determine how long ago two species diverged.

Quick check 3.12

1. **Describe** DNA hybridisation and how it provides evidence for evolution.
2. **Describe** how the number of differences in the amino acid sequence for cytochrome c can be used to establish the relationship in evolutionary terms between organisms.

Biogeography

Biogeography is the study of the distribution of organisms, both today and in the past. Biogeography provides us with additional evidence for evolution, such as when ancient fossils in one area resemble modern organisms in that same area and have a similar pattern of distribution (for example, fossil and modern platypuses are both found in Australia). The similarity of fossil and modern organisms suggests that the modern organisms have descended from ancestors living in same areas.

biogeography the study of the geographical distribution of plants and animals

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Remember that the continents were once joined in one big supercontinent, and ancestral organisms were distributed across more than one continent. When the continents split up and drifted apart, the separated populations evolved into different organisms due to reproductive isolation. However, in some cases, the selection pressures in each new area were so similar that speciation created very similar looking organisms. For example, the emu of Australia, the ostrich of Africa, the cassowary of Papua New Guinea and northern Australia and the rhea of South America are all large, flightless birds. Despite being found on different continents with oceans between them, one possible explanation for their similarity is that they descended from a common ancestor that lived on the ancient Gondwana supercontinent.

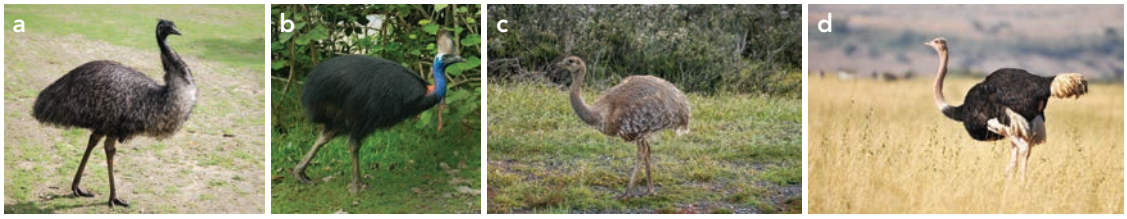

Figure 3.63 While the **(a)** emu and **(b)** cassowary can be found in Australia, **(c)** rheas live in South America and **(d)** ostriches in sub-Saharan Africa.

Quick check 3.13

1. **Define** the term 'biogeography'.
2. **Explain** how biogeography provides evidence for evolution.

VIDEO
Human evolution

Evolution of humans: Bringing it all together

In order to understand human origins, we need to first look at what humans are. Humans are in the animal kingdom, phylum Chordata, class Mammalia, order Primates, family Hominidae, genus *Homo* and species *Homo sapiens* (see Figure 3.64).

The primates living today gradually evolved over 65 million years from ancestral primates that were small tree-dwelling mammals. We did not evolve from apes and monkeys, but we share a common ancestor with them. About six million years ago, the line that led to humans is thought to have diverged from the chimpanzee line due to different habitats and different selection pressures.

This divergence led to the evolution of the earliest members of the human family, the Australopithecines, which lived in Africa between about 4 and 2 million years ago. These early hominids were bipedal, had a small brain and possessed teeth and jaws adapted to a diet that included tough plant materials. Over time, members of the human family continued to evolve and develop new adaptations, such as a larger brain and the ability to use more complex tools.

One of the most important periods of human evolution occurred around 2.5 million years ago with the emergence of the genus *Homo*. The first species in this genus, *Homo habilis*, was known for its ability to create stone tools; it had a slightly larger brain than the Australopithecines.

Over the next few million years, other species of *Homo* emerged, including *Homo erectus*, which was the first hominid to leave Africa and migrate into other parts of the world. *Homo neanderthalensis*, commonly known as the Neanderthals, was a species of hominids that lived in Europe and parts of Asia from about 400 000 to 40 000 years ago. They were named after the Neander Valley in Germany, where the first Neanderthal fossils were discovered in the mid-nineteenth century.

Neanderthals were well adapted to life in cold environments, with a stocky build and short limbs that helped to conserve body heat. They are also known to have used fire and create shelters, indicating a level of social and technological sophistication. Neanderthals produced art, made jewellery and performed burial rituals, indicating a degree of symbolic thought.

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The most recent and only surviving species of the *Homo* genus is *Homo sapiens*, which emerged in Africa around 300 000 years ago. *Homo sapiens* is characterised by its large brain, complex culture and use of language. Genetic studies have shown that Neanderthals interbred with modern humans, as evidence of their DNA has been found in the genomes of non-African humans. However, they eventually became extinct around 40 000 years ago for reasons that are not entirely clear, although factors such as climate change, competition with modern humans, and disease have been suggested as possible contributing factors.

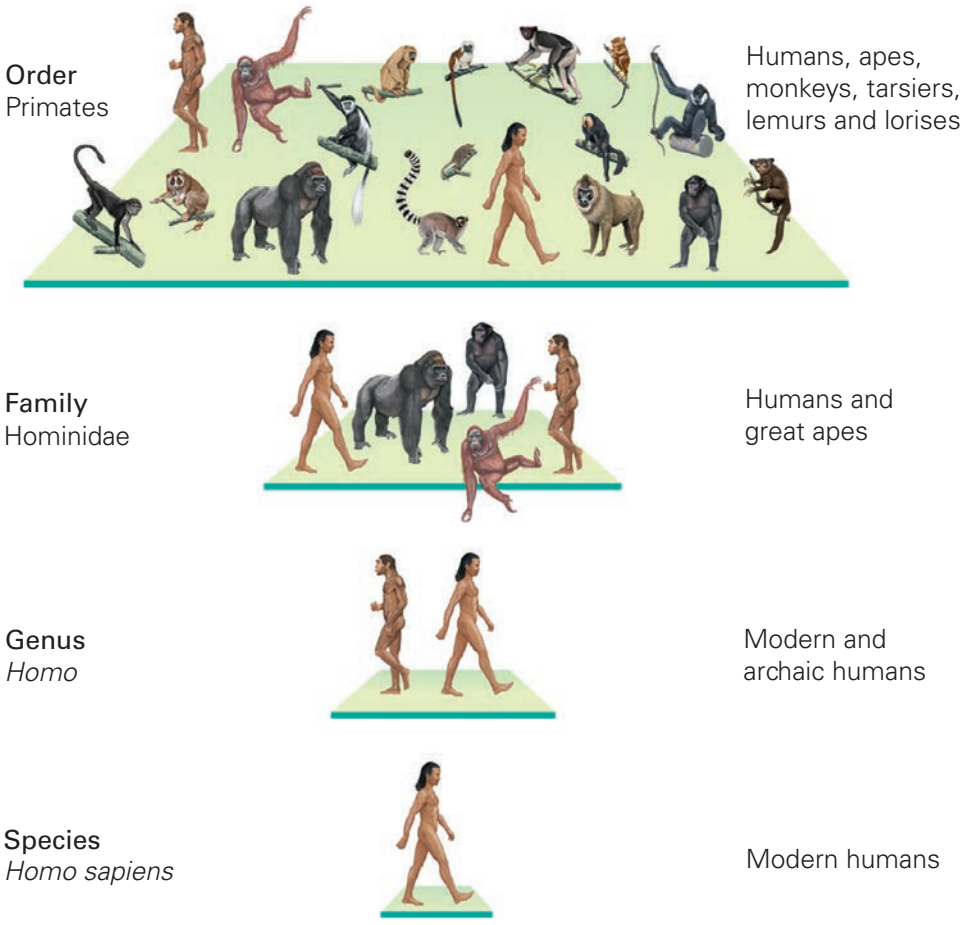

Figure 3.64 Classification of *Homo sapiens* within the order Primates

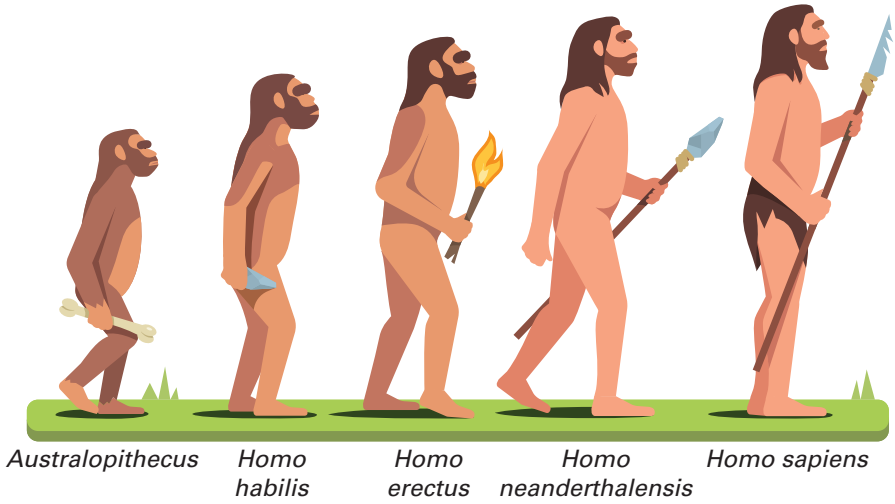

Figure 3.65 The biologist and anthropologist Thomas Henry Huxley (1825–1895) was the first to suggest that humans and other species were related.

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Explore! 3.8

Evidence for human evolution

In this section, you have learned about the different ways that we can gather evidence about evolution: palaeontology, comparative anatomy, embryology, molecular biology and biogeography. However, we have not investigated how they have informed us about human evolution.

Figure 3.66 An archaeological excavation uncovers human remains.

1. Research the fossil evidence of human evolution. Summarise what fossils teach you about the evolution of humans and use pictures to illustrate what you find.
2. Research homologous and analogous structures related to human evolution. Summarise what comparative anatomy teaches you about the evolution of humans and use pictures to illustrate what you find.
3. Research the DNA evidence of human evolution. Summarise what DNA teaches you about the evolution of humans and use pictures to illustrate what you find.

Go online to access the interactive section review and more!

Section 3.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 3.3 questions

Remembering

1. **Name** five sources of evidence for evolution.
2. **Recall** what is meant by the term 'fossil'.
3. **Recall** what the term 'biogeography' refers to.

Understanding

4. **Describe** analogous structures, providing an example.
5. **Explain** how DNA hybridisation can show that two organisms share a common ancestor.
6. **Explain** how the scales of reptiles and the feathers of birds are considered homologous structures (see Figure 3.67).

Figure 3.67 (a) Bird feathers and **(b)** reptile scales

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Applying

7. **Summarise** why fossils of soft-bodied organisms are relatively rare.
8. Figure 3.68 represents the layers of rock found within a cave. **Identify** the layer (1 to 5) where you would expect to find the oldest group of fossils, giving reasons for your answer.

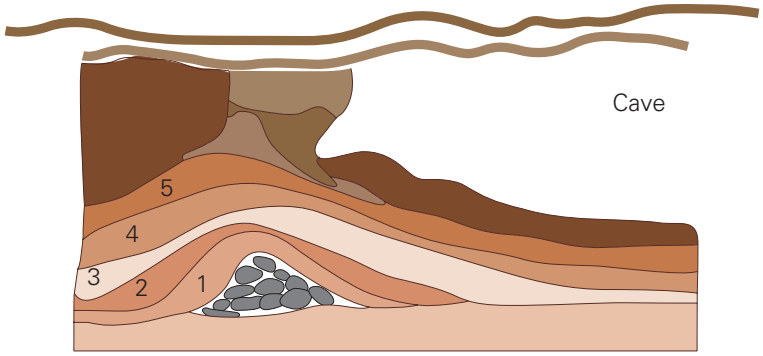

Figure 3.68 Layers of rock within a cave

9. **Distinguish** between absolute and relative dating techniques.

Analysing

10. Figure 3.69 shows a timeline for the evolution of some dinosaurs. The average mass of each dinosaur is shown in brackets under its name. **Identify** the appropriate dinosaur for each statement.
    a) The dinosaur that lived the longest time ago is the _____.
    b) The dinosaur/dinosaurs that evolved from *Agilisaurus* is/are the _____.
    c) The dinosaur from which *Camarasaurus* evolved is the _____.
    d) The dinosaur with the largest average mass is the _____.

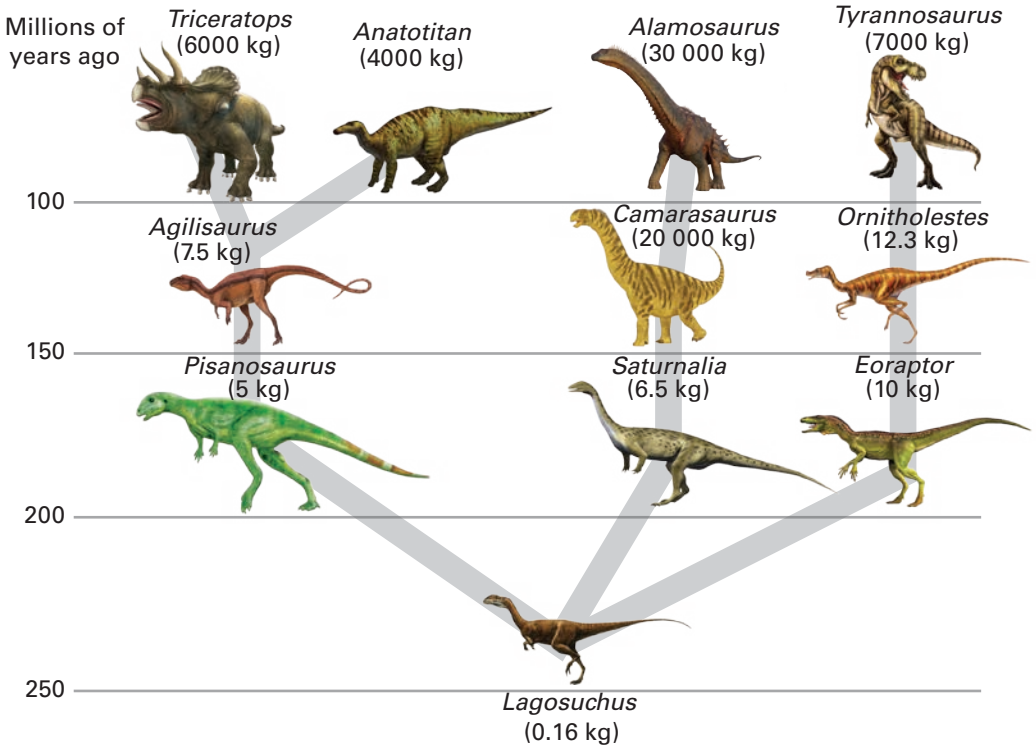

Figure 3.69 Timeline for the evolution of some dinosaurs

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11. The chronogram in Figure 3.70 shows the evolutionary relationship between some freshwater fish.

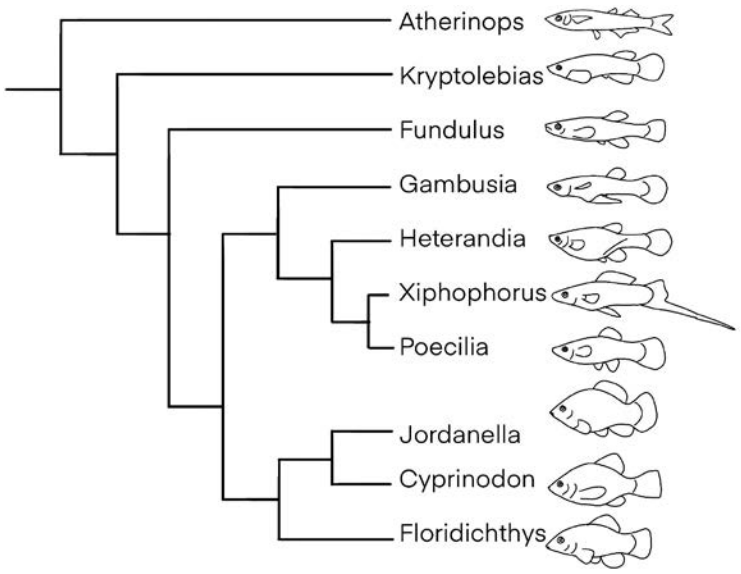

Figure 3.70 Chronogram showing evolutionary relationship between some freshwater fish

a) **Infer** which genus is most distantly related to *Poecilia*.
b) Between the genera *Cyprinodon* and *Fundulus*, **infer** which is more closely related to *Poecilia*.

Evaluating

12. The table below shows the number of nucleotide differences between a region of mitochondrial DNA in humans, chimpanzees and a Neanderthal.

	Human 2	Chimpanzee 1	Chimpanzee 2	Neanderthal
Human 1	15	77	76	20
Human 2		79	80	27
Chimpanzee 1			23	72
Chimpanzee 2				71

a) Based on the table, **deduce** which organism is most closely related to the Neanderthal.
b) Based on the table, **deduce** which organism is the least closely related to the Neanderthal.
c) **Decide** which method could be used to estimate the absolute age of a Neanderthal fossil.
d) **Decide** which method could be used to estimate the relative age of a Neanderthal fossil.

Figure 3.71 A skull of *Homo neanderthalensis*

13. **Propose** how you would investigate whether birds are more closely related to mammals or reptiles. Include what evidence you would expect if the organisms were related or not related.

14. **Construct** a concept map that shows the links between the different ways we can gain evidence for evolution. Include information on how each method sheds light on evolution.

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Chapter review

Chapter checklist

Success criteria		Linked questions
3.1	I can recall the definition of evolution.	1
3.1	I can describe the five drivers of evolution (mutation, gene flow, genetic drift, natural selection, sexual reproduction).	2, 11
3.1	I can describe the concept and importance of biodiversity.	9
3.1	I can describe some reasons for species becoming endangered or extinct and propose ways to minimise this problem.	17
3.2	I can recall the steps in the process of natural selection.	6, 7, 14
3.2	I can explain how speciation occurs.	10
3.2	I can distinguish between artificial and natural selection.	12
3.3	I can recall the main evidence for evolution.	3
3.3	I can describe how a fossil forms.	5
3.3	I can describe that radiometric dating of fossils relies on nuclear decay processes.	3

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review

Review questions

Remembering

1. **Define** the terms 'evolution', 'gene flow', 'genetic drift' and 'natural selection'.
2. **Recall** the main causes of variation among organisms.
3. Scientists excavated an abandoned quarry and found a set of dinosaur footprints that could be up to 145 million years old. The trails of 90 uninterrupted prehistoric footprints are thought to have been made by a sauropod – a class of heavy dinosaurs with long necks and tails. **Recall** how the quantity of the isotope carbon-14 in a fossil can be used to accurately date a fossil.

Understanding

4. **Describe** what is meant by the concept of variation in the field of evolution.
5. **Describe** how a fossil found in sedimentary rock is formed.
6. **Explain** how the camouflage of organisms supports the idea of natural selection.
7. **Explain** why 'survival of the fittest' does not necessarily mean survival of the biggest and strongest.
8. **Explain** how amino acid sequences can provide evidence for evolution.
9. **Describe** the importance of biodiversity.

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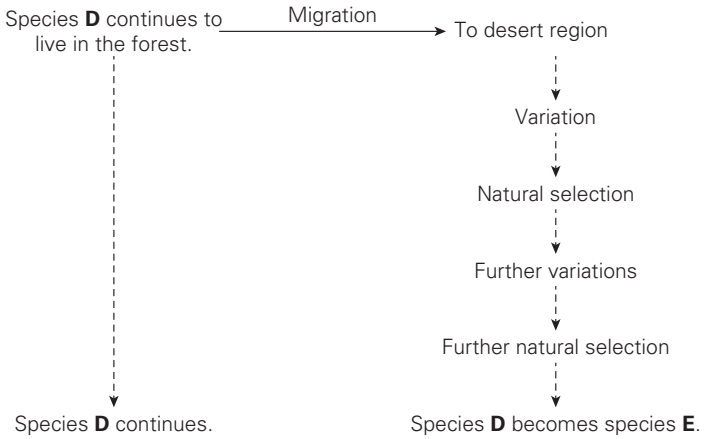
10. The following diagram represents the process of speciation.



Explain, using the information from the diagram, the key drivers behind the creation of the new species E in the desert.

11. **Explain** how mutations contribute to the process of evolution.

Applying

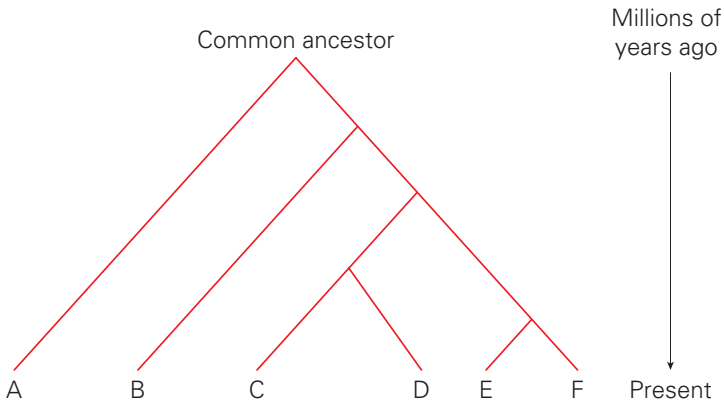
12. Using diagrams, **discuss** how rabbits may have become resistant to the deadly myxoma virus, which was released in Australia to try to control rabbit populations.

13. **Discuss** how scientists use information gained from sedimentary rock to arrange fossils into an evolutionary sequence over time.

Analysing

14. **Critique** the process of artificial selection.

15. The following diagram shows the evolutionary tree for six organisms from a common ancestor.



a) According to the diagram, **identify** the present-day organism that is least closely related to the others. Justify your response.

b) **Infer** which two organisms have the most recent common ancestor, giving reasons for your response.

c) **Propose** a reason why members of the new species E cannot breed successfully with species D.

Evaluating

16. **Decide** why scientists want to find out about evolution.

17. **Discuss** why we should conserve species.

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Data questions

Geospiza fortis is a ground finch that feeds on seeds on Daphne Major, one of the Galápagos Islands. From 1975 to 1977, the island experienced a severe drought. The graphs in Figure 3.72 show features of the *G. fortis* population and the island's seed supply during these years.

1. **Calculate** the percentage decrease in population size between July 1975 and December 1977.

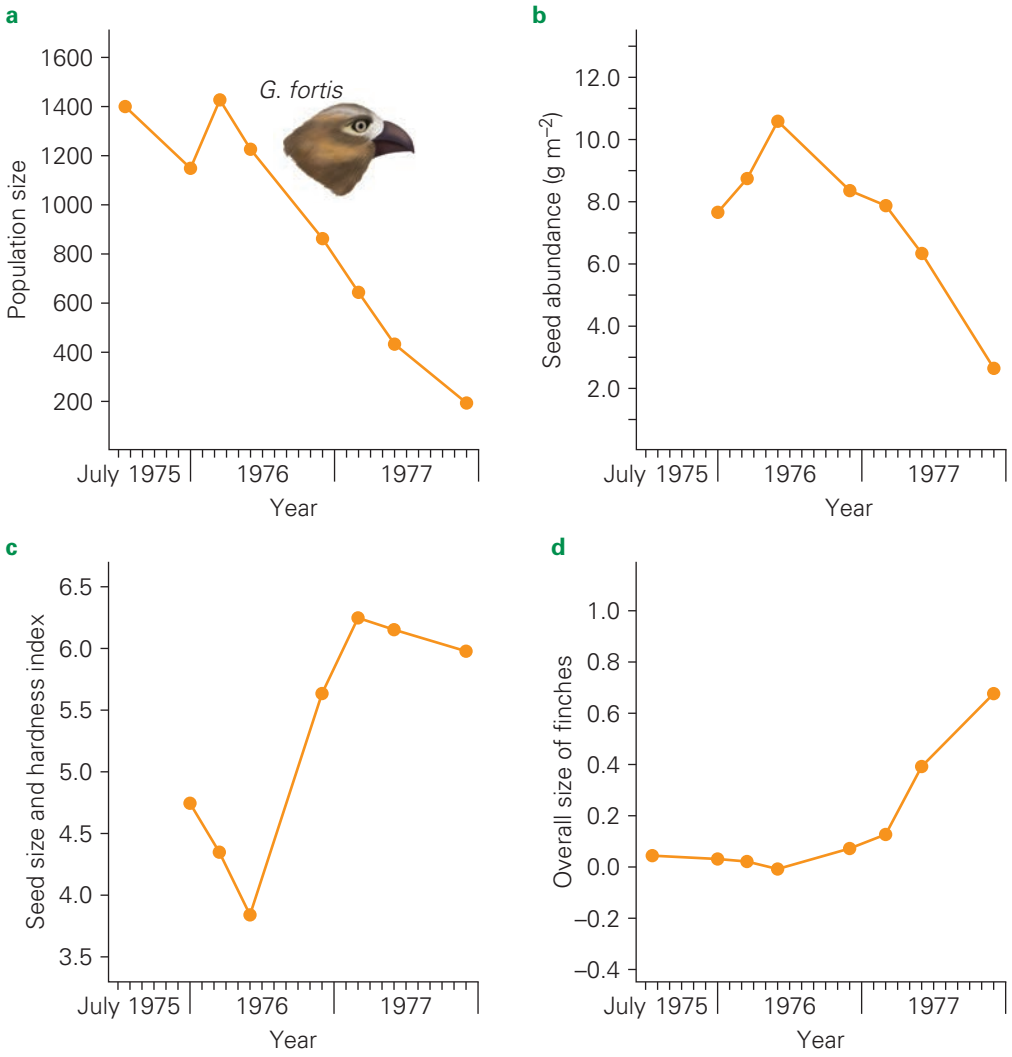

Figure 3.72 Features of the *Geospiza fortis* population and the seed supply on Daphne Major

2. **Identify** any relationships you can find in the graphs.
3. **Infer** why the size of the finches increased as the drought continued.

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STEM activity: Designing a wheelchair to aid dogs with genetic problems

Background information

Individuals in a species become well adapted to their environment by the process of natural selection. In this process, individuals with characteristics that allow them to thrive in the environment are selected for, and they pass their suitable genes onto subsequent generations. However, individuals within a species being too similar genetically can be detrimental to a species' survival. If the environment changes, genetic variation within a species gives it a better chance of survival because there are individuals that can cope better with the changed environment. A lack of genetic variation can result in extinction from an environmental change.

Inbreeding occurs when genetically similar individuals from a species breed with each other. There are many examples of inbreeding in humans and other species that are bred selectively, like dogs. In these cases, the problem is not that a population could be wiped out by an environmental change, but that genetic conditions that would be very rare in wider populations continue to be passed onto subsequent generations.

A famous example of this occurred with haemophilia, a condition resulting from a mutation on the X chromosome. In people with this condition, blood does not clot properly, so injury can cause excessive bleeding. Haemophilia spread throughout European royal families in the nineteenth and twentieth centuries because of arranged marriages among the related royal families.

Humans have bred dogs for thousands of years, originally to serve a specific purpose or job like herding and hunting. All modern dog breeds exist because of human selective breeding. Unfortunately, many pure-bred dogs suffer from genetic conditions because of inbreeding. For example, pure-bred dachshunds commonly suffer from knee problems because of their short legs and non-ideal angle for the knees. They also often have hip dysplasia and spinal problems because of their long bodies, and eye problems like cataracts.

Figure 3.73 (a) Dachshunds are prone to numerous genetic diseases because their signature long bodies and tiny legs were developed by inbreeding. **(b)** Dachshunds are not the only dog breed that may need the aid of a wheelchair.

While dog owners can take preventive measures to reduce the effects of these disorders, often reactive treatment is the method used to give affected dogs a good quality of life. Wheelchairs are a potential solution to help with mobility for dachshunds that have hip and knee problems.

DESIGN BRIEF

Design a wheelchair to aid dachshunds with genetic knee and hip problems.

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Activity instructions

In small groups, research the features of dog wheelchairs. You may like to put together a collection of different designs to help you decide which features you would like to include in your own design.

Draw your chosen design and label its features and the materials you intend to use. You will need to consider the method of attaching the wheelchair to the dog and whether the dog's legs will hang down or be supported on a platform. You will also need to think about the best way to make it comfortable for the dog. Some research into the specific genetic problems occurring in dachshunds may be necessary to make sure you are catering for the dogs' needs.

Your wheelchair will need to be sturdy, so remember to use appropriate shapes and bracing to achieve the right strength for your design.

Suggested materials/presentation formats

- cardboard
- fabric/felt
- glue
- scissors
- wheels
- icy-pole craft sticks
- elastic bands
- straws
- sticky tape

Research and feasibility

1. Research and list all the features that make a wheelchair comfortable and functional.

Feature	Functionality
e.g. padded seat	Comfortable to use for long amounts of time

2. Research dog wheelchairs that are currently available and how they are used for dogs with hip and knee problems. List all the problems that exist with current models and solutions that could be included.
3. Research the dachshund breed and make note of the size of the dogs and their common hip and knee problems.

Design and sustainability

4. Design a prototype of a wheelchair specifically for a dachshund. Annotate your diagram and include all design features and the functionality it provides.
5. Reflect on the sustainability of the materials used, and the life cycle of the wheelchair prototype regarding its durability.

Create

6. Construct the prototype using available materials.

Evaluate and modify

7. Describe any difficulties you came across when constructing your model. Explain how you overcame these difficulties.
8. Propose some improvements to the design of your wheelchair to improve comfort and functionality.
9. Depending on the size of your model, you may be able to test it by using your wrist or palm as the back of the dog and your index and middle fingers as the front legs to pull it along. Test it with different amounts of downward pressure to represent different dog sizes and weights. Comment on how your wheelchair fared in your tests.

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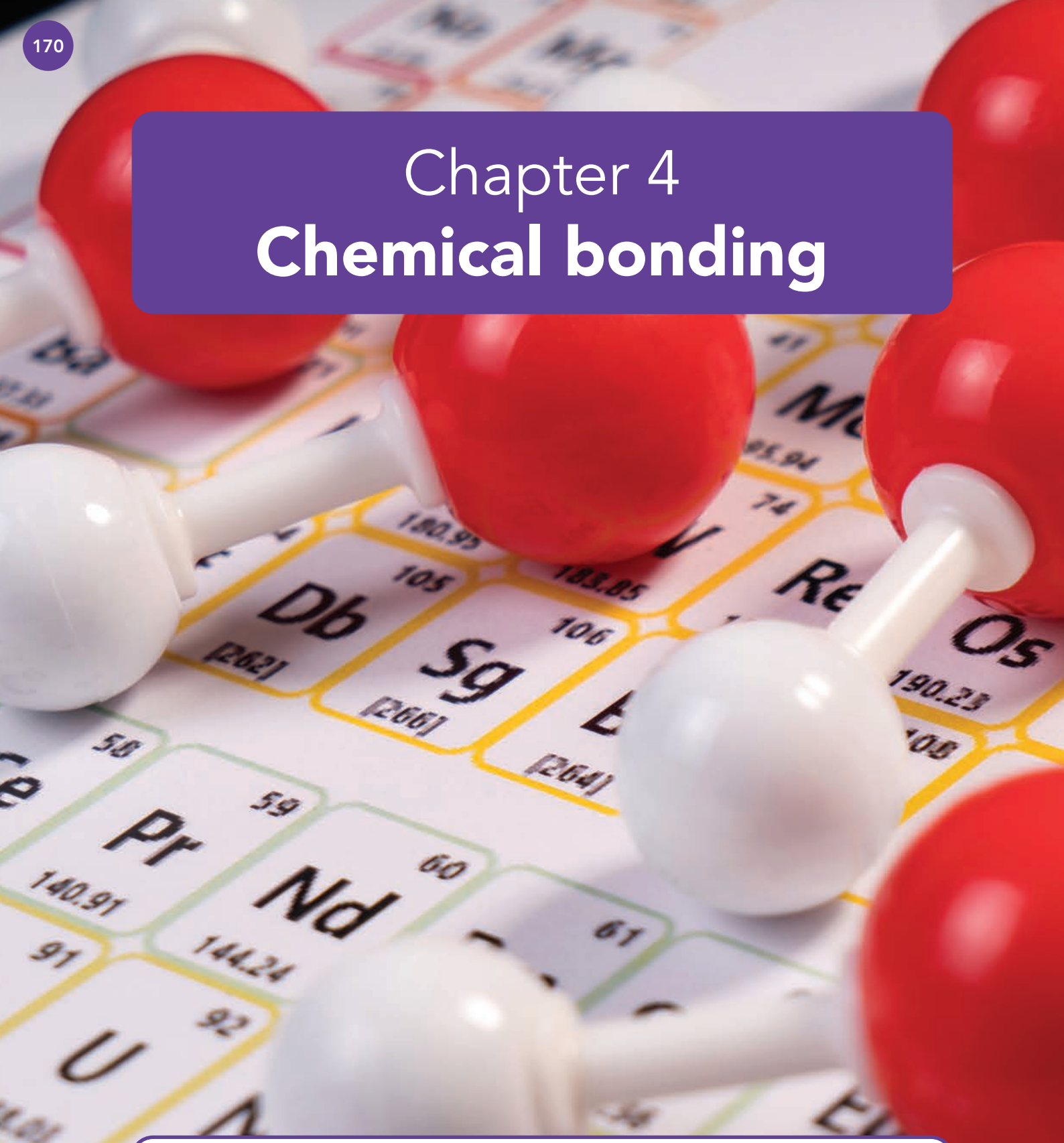
Chapter 4
Chemical bonding



Chapter introduction

Elements rarely exist naturally as individual atoms, but rather as atoms chemically bonded together. Chemical bonds are a result of the sharing or transfer of valence electrons between atoms. Metal atoms form metallic bonds, while non-metal atoms generally form covalent bonds. The combination of metal and non-metal atoms generally forms ionic bonds. The type of chemical bonding present is responsible for the properties of chemical substances as well as how they are named and how the chemical formula is written.

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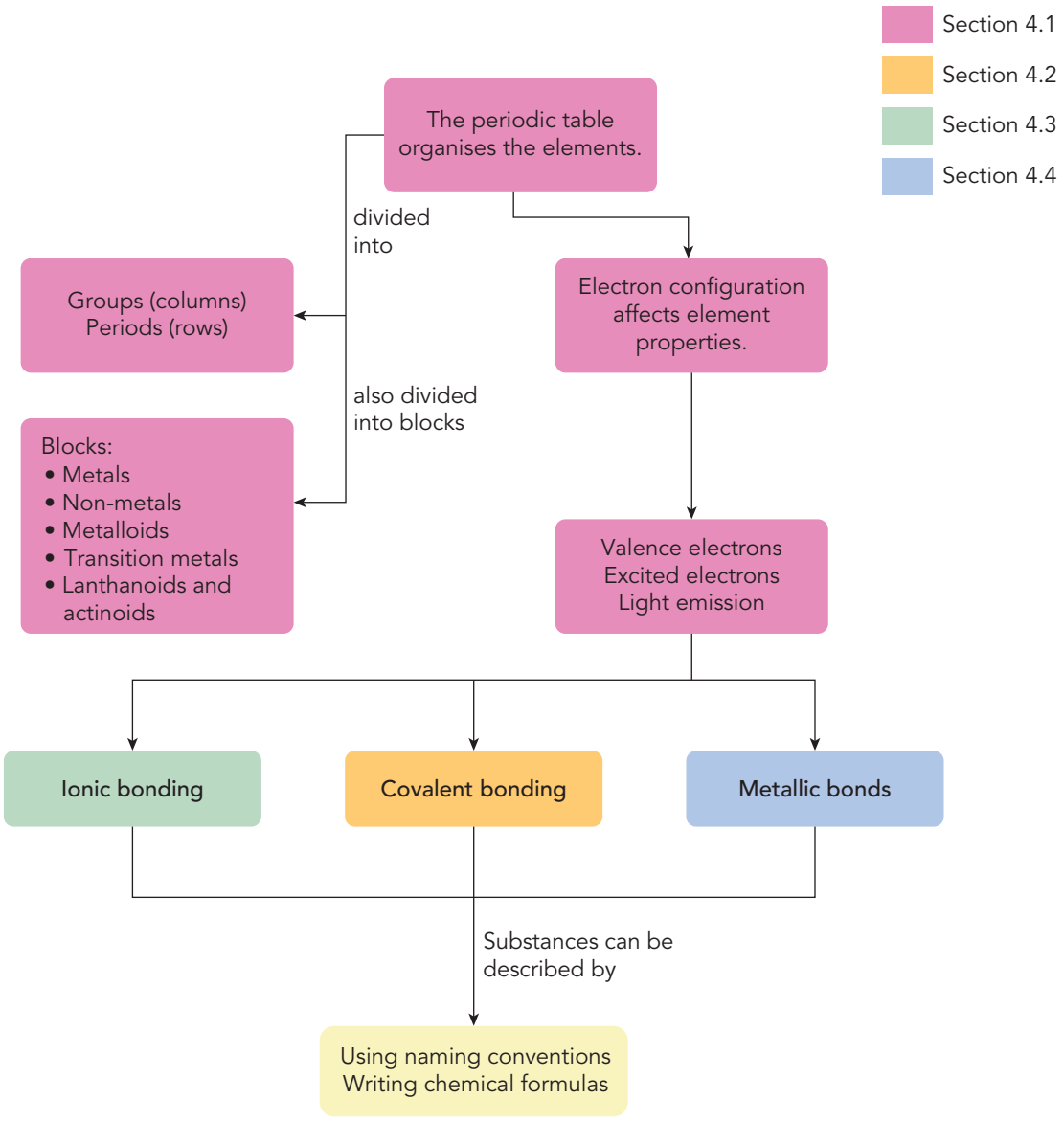
Chapter map



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Curriculum content

Chemical sciences	
The ability of atoms to form chemical bonds can be explained by the arrangement of electrons in the atom; ionic bonding involves electron transfer and covalent bonding involves sharing of electrons	
• comparing ionic and covalent bonds	4.1, 4.2, 4.3
• using the naming conventions for ionic and covalent compounds	4.2, 4.3
• representing compounds using chemical formulas and models	4.3, 4.4
• using the periodic table and a table of common ions to write chemical formulas to represent ionic compounds	4.3

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Glossary terms

anion
bonding pair
cation
chemical bond
covalent bond
crystalline
delocalised electron
diatomic
ductile
electron configuration
electron shell
electrostatic attraction
ground state
ion
ionic bond
lattice
lustrous
malleable
metallic bond
metalloids
molecular compound
molecular element
molecular formula
molecule
octet rule
polyatomic ion
transition metals
valence electrons
valence shell

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4.1 Electron configuration

Learning goals

At the end of this section, I will be able to:

1. Identify metals, non-metals and metalloids by their position on the periodic table.
2. Write an electron configuration for atoms and ions up to 20 electrons.

The periodic table provides a lot of information on the composition of atoms of elements. In previous years you have learned that the atomic number (Z) is unique to each element and denotes the number of protons in a nucleus. The relative atomic mass (A_r) gives information on the average mass of protons and neutrons in the atom's nucleus from all naturally occurring isotopes, and in a neutral atom, the number of protons is also equal to the number of electrons. The periodic table organises the elements into groups (columns) and periods (rows) due to similarities and differences in their physical and chemical properties.

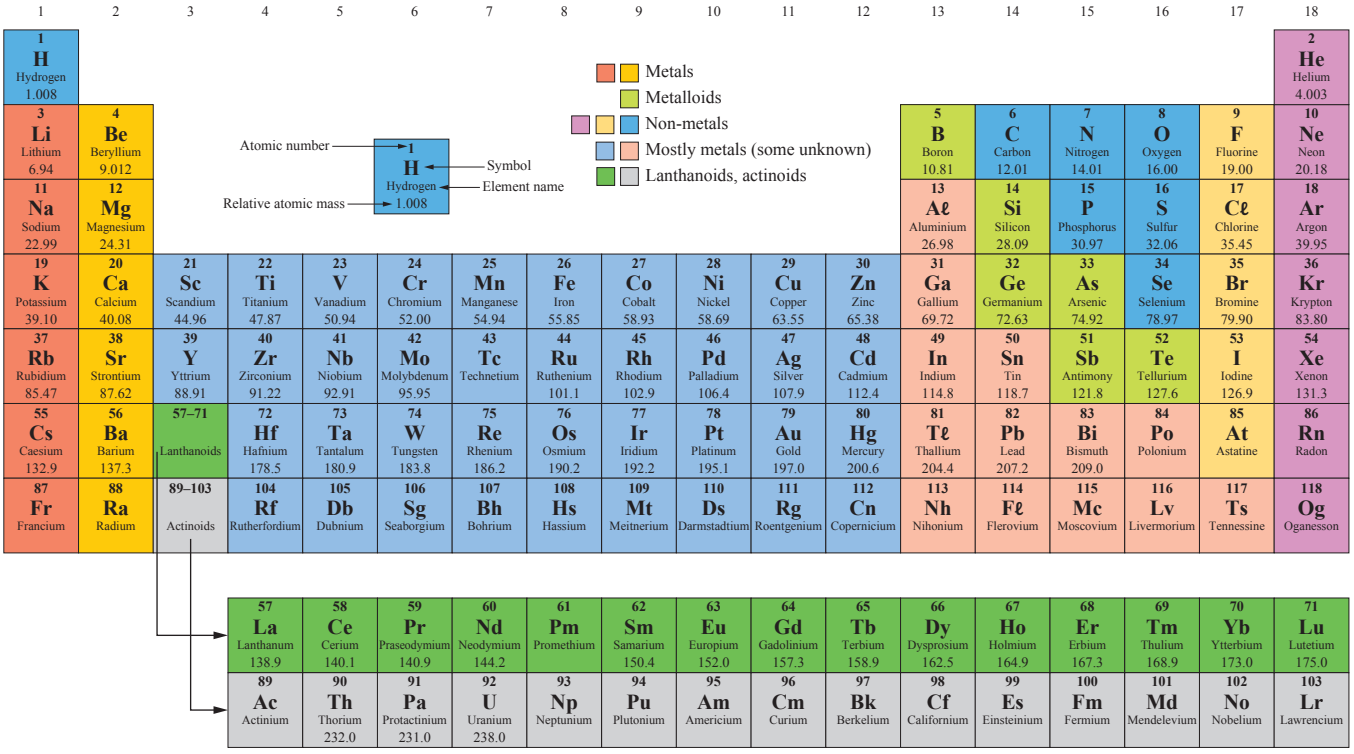

Figure 4.1 The periodic table. See the appendix for a larger version.

In this section, we will also identify the trend of electron configuration in the periodic table. To make this task easier, the periodic table will first be broken into different blocks of elements including metals, metalloids and non-metals based on their physical properties.

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Blocks of the periodic table

VIDEO
Reactive metals

Metals

Metals make up most of the elements in the periodic table. In fact, 93 of the 118 known elements are metals, and they sit on the left-hand side of the table. Almost all metals in the periodic table are solids at room temperature; the exception is mercury (Hg), which is a liquid.

Metals have particular properties; they:

- are **lustrous**
- have high melting and boiling points
- are malleable, meaning they can be beaten into shapes
- are ductile, meaning they can be drawn out into long, thin wires
- are good conductors of heat and electricity.

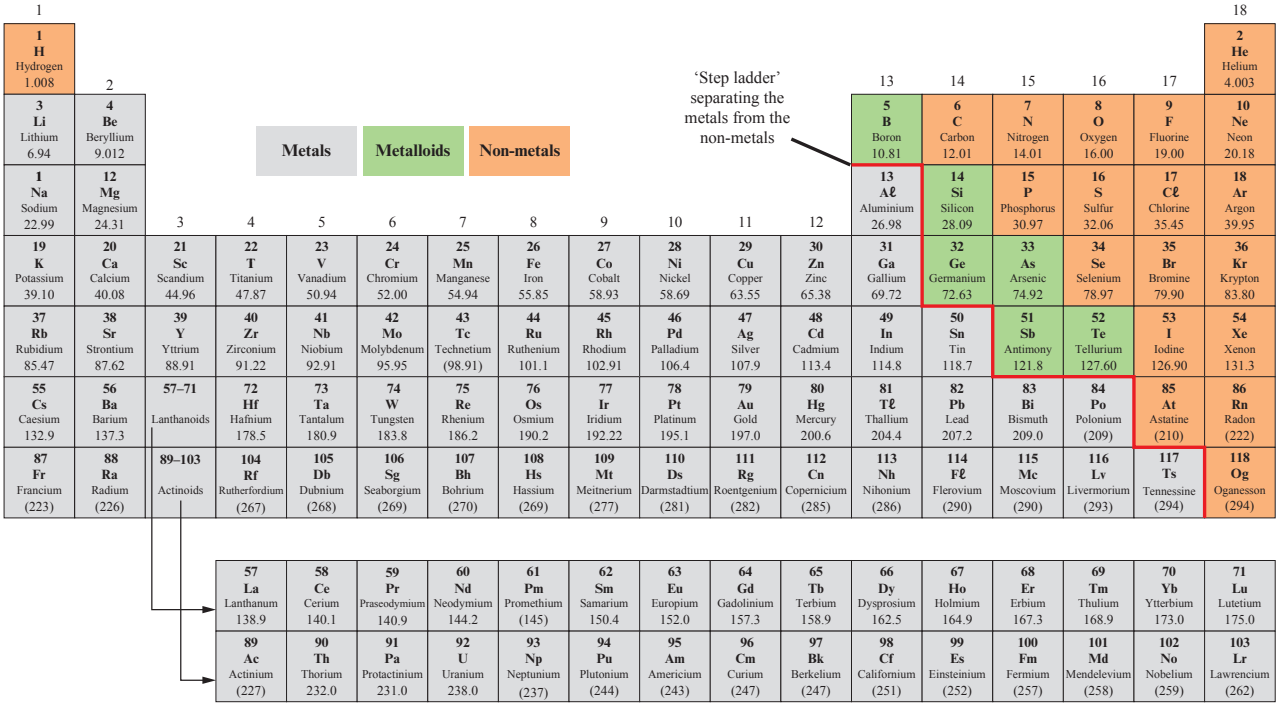

Figure 4.2 Three colours show the elements classified as metals, non-metals and metalloids.

Transition metals

lustrous
in metals, having a shiny surface

transition metals
the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

The **transition metals** are a large block of metals containing the elements from groups 3 to 12 in periods 4 to 7 (see Figure 4.2). These metals are generally hard and dense, but chemical reactivity does vary among the transition metals. Iron (Fe), silver (Ag), chromium (Cr) and zinc (Zn) are all transition metals but may differ in reactivity.

Figure 4.3 Mercury is the only metal that is liquid at room temperature.

Lanthanoids and actinoids

The lanthanoids and actinoids are elements that sit between the group 2 metals and the transition metals. They are in periods 6 and 7, respectively, but they are placed at the bottom of the periodic table so that the table is easier to work with. If they were not placed below the periodic table, it would be extended horizontally and wouldn't fit nicely on a page!

The lanthanoids include elements with atomic numbers from 57 to 71 (in period 6) and are sometimes called the 'rare earth elements' along with scandium (Sc) and yttrium (Y), two other elements commonly found in ores containing the lanthanoid elements. The lanthanoids are lustrous grey metals.

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The actinoids contain elements with atomic numbers from 89 to 103 (in period 7). They are primarily synthetic elements with a few exceptions, such as uranium. In fact, all elements with a higher atomic number than uranium are synthetic as their larger nuclear masses are highly unstable. The instability of these elements, including uranium, can be manipulated to produce radioactive atoms that can release energy in nuclear reactors.

Science inquiry 4.1

Luminescent lanthanoids

The lanthanoids are fascinating elements; each has unique luminescent properties. The light emission of the lanthanoid elements displays sharp line-like emission bands of very specific wavelengths. This gives the lanthanoids rather pure colours of visible light emission, which makes them useful for applications such as the LED pixels in mobile phones and televisions. For example, europium (Eu) emits red light, terbium (Tb) green light and thulium (Tm) blue light.

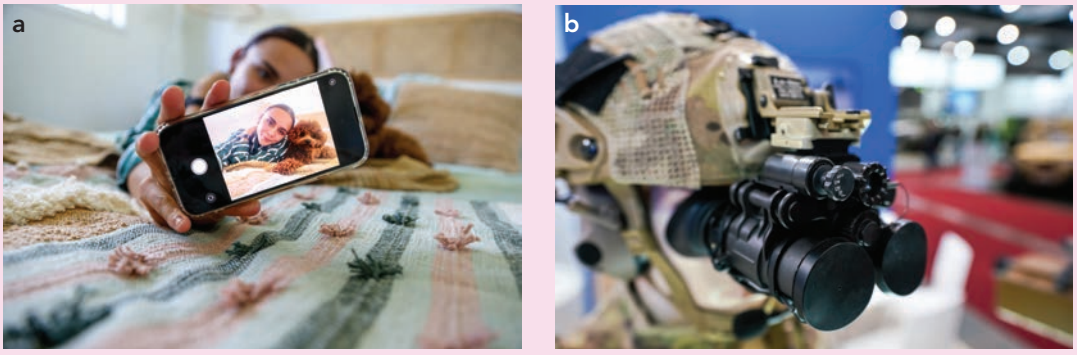

Figure 4.4 Lanthanoids are responsible for light emission in **(a)** smartphones and **(b)** torches for night-vision goggles.

The efficiency and long lifetime of their emissions make the lanthanoids ideal candidates for use in new light-emission materials.

An example is the use of lanthanoids such as ytterbium that emit near-infrared (NIR) light. These wavelengths of light are not in the visible spectrum and so cannot be seen by humans with the naked eye, but they can be seen by some nocturnal animals. This is the type of light that night-vision goggles detect and translate to green visible light on a screen for humans to view, making vision on a dark night possible. On some nights there is not even enough NIR light to brighten the surroundings for night-vision goggles. On those occasions, NIR torches, based on NIR-emitting lanthanoids, can make it possible to use night-vision goggles.

Researchers are continuing to make even brighter emissions and to use these cutting-edge materials for devices such as mobile phones that use visible light and night-vision goggles that use NIR radiation.

Quick check 4.1

1. **Complete** this sentence: The block of elements in the middle of the periodic table, containing groups 3 to 12, is called the _____.
2. **Identify** which of the following is a transition metal: sodium (Na), tungsten (W), europium (Eu), aluminium (Aℓ).
3. **State** if the following statement is true or false.
   Lanthanoids are part of the sixth period on the periodic table.

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Non-metals

Non-metals (except hydrogen) are located on the right-hand side of the periodic table. There are fewer non-metals than metals, but their properties are much more varied. The naturally occurring non-metals consist of one liquid – bromine (Br) – five solids and 11 gases at room temperature.

Figure 4.5 The non-metal sulfur is a yellow solid.

In general, non-metals:

- are dull
- are brittle, meaning they will shatter when bent or struck with something hard
- have low melting and boiling points
- are poor conductors of heat and electricity.

Metalloids

metalloids elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

The elements located between the metals and non-metals are called **metalloids**. Six elements are typically classified as metalloids: boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb) and tellurium (Te). The metalloids share some properties of metals and non-metals. For example, germanium has a lustrous grey appearance, like a metal, but is a non-conductor of electricity and is brittle like the non-metals. As metalloids are not metals, we will treat them as non-metals in chemical bonding later in this chapter.

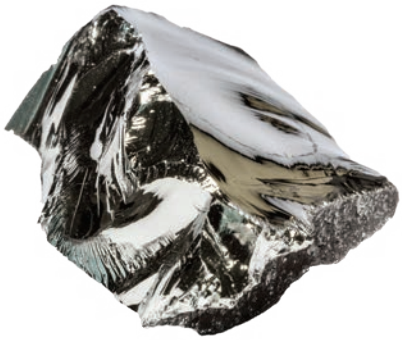

Figure 4.6 Germanium is a lustrous metalloid.

Quick check 4.2

1. **Recall** the side of the periodic table where metals are located.
2. **Select** the correct word to complete this sentence:
   The name given to elements which behave like metals and non-metals is _____.
3. **Decide** whether the following statements are true or false. If false, provide reasons why.
   a) Metals have high melting points.
   b) Almost all metals are liquids at room temperature.
   c) There are more non-metals than metals on the periodic table.
   d) There are only two liquid elements on the periodic table at room temperature.

Table 4.1 summarises the properties of metals and non-metals.

Metals	Non-metals
Lustrous	Dull
High density	Low density
Good conductors of heat and electricity	Poor conductors of heat and electricity
Malleable and ductile	Brittle
High melting and boiling points	Low melting and boiling points

Table 4.1 Properties of metallic and non-metallic elements

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Electron shells

An atom of an element is made up of a nucleus of positively charged protons and neutral neutrons surrounded by orbiting negatively charged electrons. In this chapter, electrons will be shown orbiting the nucleus in different energy levels, called 'shells'. This shell configuration is shown in Figure 4.7 for the element lithium (Li) with three electrons.

As electrons are negatively charged, they repel each other while moving around the nucleus. Therefore, electrons organise themselves in spaces around the nucleus to minimise the possible repulsion from other electrons. This results in **electron shells**, which are shown as different distances from the nucleus and can hold different maximum numbers of electrons (see Figure 4.8).

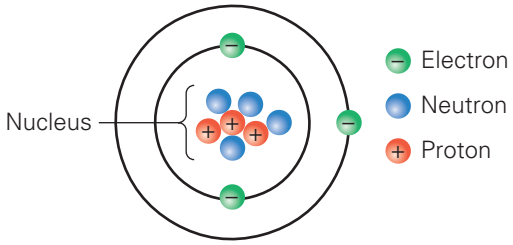

Figure 4.7 An atomic model for lithium

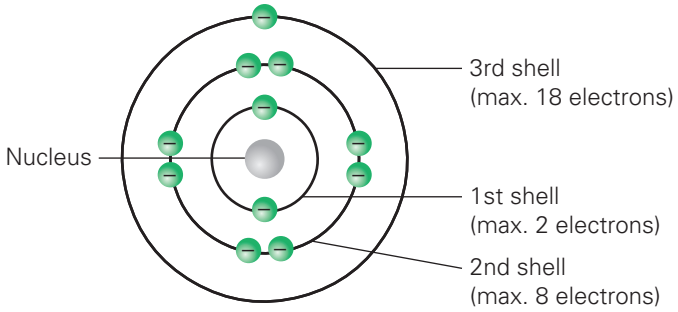

Figure 4.8 Arrangement of electrons in shells around the nucleus

electron shell the energy level in which the electrons orbit the nucleus of an atom

octet rule atoms tend to lose, gain or share outer shell electrons to achieve eight electrons in their outer shell

As negatively charged electrons are attracted to the positively charged nucleus, it takes more energy to move them away from the nucleus to an electron shell at a further distance. Therefore, electrons situated in shells further away from the nucleus are considered to be at higher energy levels than electrons in closer shells.

The first electron shell can hold a maximum of two electrons in its small area before the repulsion becomes so great that electrons must move to a second shell. The second shell can hold a maximum of eight electrons, the third shell up to 18 electrons and the fourth shell up to 32 electrons.

However, electrons do not fill shells completely before moving to a higher energy shell; in fact, the order of filling is 2,8,8,2 for the first 20 electrons. This occurs because electrons repel each other, and it requires less energy to place them in a space with less repulsion, even if it is a higher energy level. This phenomenon, in which electrons tend to fill electron shells to a stable number of eight electrons first (or two electrons in the first shell), is referred to as the **octet rule**. Note that further electron shells exist but are not covered here.

Table 4.2 summarises the maximum number of electrons in each electron shell and the actual order of filling.

Electron shell	Maximum number of electrons	Order of filling (from top down)
First (lowest energy level)	2	2
Second	8	8
Third	18	8
Fourth (higher energy level)	32	2

Table 4.2 The maximum number of electrons and order of filling in each electron shell

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Quick check 4.3

1. **Describe** how electrons arrange themselves in an atom.
2. **Complete** the sentence by circling the correct italicised words:
   The electron shell *closest to/furthest from* the nucleus is the *first/last* to be filled.
3. **Identify** the maximum number of electrons in the following shells:
   a) first shell
   b) second shell
   c) third shell
   d) fourth shell

Electron configurations of the elements

electron configuration the arrangement of an atom's electrons in the shells around the nucleus

ground state the lowest energy level of an atom

The **electron configuration** shows how the electrons for a particular element are arranged. When electrons fill shells, they always start from the lowest energy level (the electron shell closest to the nucleus). This means that atoms are always at their lowest energy level or **ground state**.

An atom of magnesium (Mg) has an atomic number of 12, so it must have 12 electrons. Its electrons therefore fill the electron shells in the order 2,8,2, and this is known as the electron configuration. This shows that there are two electrons in the first shell, eight in the second and two in the third. Figure 4.9 shows the electron arrangement of a magnesium atom. The sum of all the numbers in the electron configuration should add up to the total number of electrons in that atom. Calcium fills its shells with 20 electrons in the order 2,8,8,2 (see Figure 4.10), requiring a fourth shell of electrons. This order of filling electron shells works consistently until we reach the transition metals. For example, scandium (Sc), with 21 electrons, will actually begin filling its third shell again, that is, 2,8,9,2. Electron configurations with more than 20 electrons are beyond the scope of this course as the order of electron shell filling can become quite complicated.

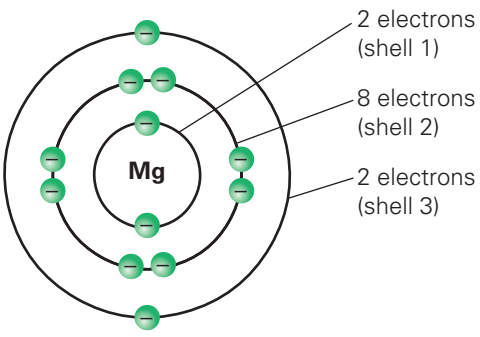

Figure 4.9 The electron configuration of magnesium (2,8,2)

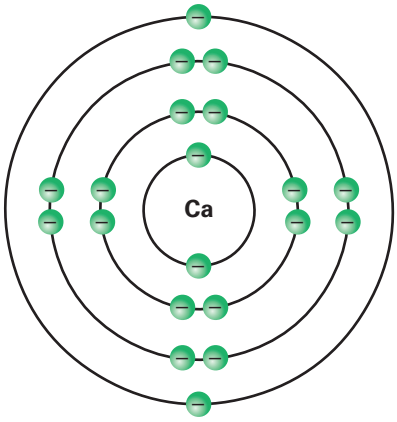

Figure 4.10 The electron configuration of calcium (2,8,8,2)

Making thinking visible 4.1

+1 Routine: Electron configuration

Consider what you have read about the electron configuration of elements.

1. **Recall**: Generate a list of ideas that you feel are important on this topic.
2. **Add (+) 1**: Pass your ideas to a partner and receive a list of ideas from another partner. Add one new idea to this list.
3. **Act**: Pass the list back to your partner and read through the new addition to your own list. Write down any new ideas you have thought of as well.

The *+1 Routine* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Worked example 4.1

Writing the electron configuration

Write the electron configuration for an atom of chlorine.

Working	Explanation
Z(Cℓ) = 17 So, number of electrons = 17	The atomic number (Z) = the number of electrons in a neutral atom.
Chlorine has 17 electrons; therefore, the electron shells are filled: 1st: 2 electrons 2nd: 8 electrons 3rd: 7 electrons	The 17 electrons fill electron shells in the order of 2,8,8,2.
Electron configuration: 2,8,7	The electron configuration is written with the number of electrons in each shell separated by a comma, i.e. 2,8,8,2.

Quick check 4.4

1. **State** the name given to atoms when they are at their lowest energy level.
2. **State** the number of electrons in an element with an electron configuration of 2,8,5.
3. **State** the atomic number of an element which has 18 electrons.
4. **State** the electron configuration of an oxygen atom.

Electron configuration and element properties

The way atoms react is largely determined by the arrangement of their electrons. Protons and neutrons are situated in the centre of the atom and therefore are not affected when particles collide during chemical reactions. It is the electrons, and specifically the outermost electrons, which are the most affected, and are therefore of most interest to chemists predicting chemical reactivity.

valence electrons the electrons in the outer shell of an element

valence shell the outermost shell of the atom that contains electrons

The outermost electrons in an atom are called **valence electrons** and exist in the **valence shell**.

The biggest influence on an element's chemical and physical properties is the number of electrons in the valence shell. This means that elements with the same number of valence electrons are grouped together in the periodic table with similar chemical properties. For example, all elements in group 1 have one valence electron. Their electron configurations all end in the number 1.

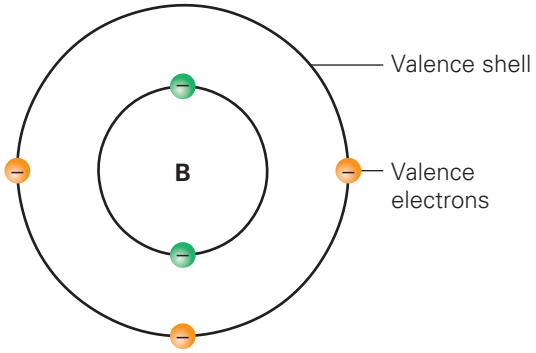

Figure 4.11 Boron (B) has an electron configuration of 2,3. It therefore has three valence electrons (shown in orange).

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This trend in generally true for many groups on the periodic table:

- Group 1: 1 valence electron
- Group 2: 2 valence electrons
- Group 13: 3 valence electrons
- Group 14: 4 valence electrons
- Group 15: 5 valence electrons
- Group 16: 6 valence electrons
- Group 17: 7 valence electrons
- Group 18: 8 valence electrons, with the exception of helium (He), which has 2 valence electrons.

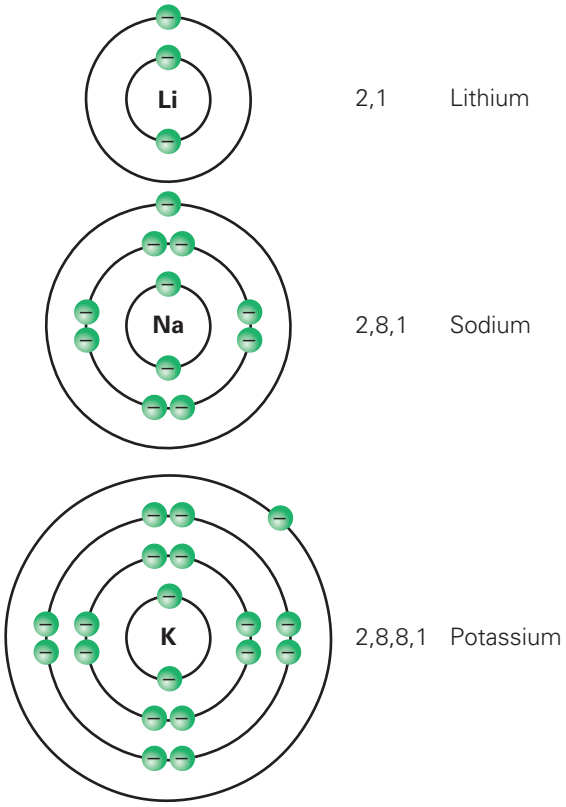

Figure 4.12 These elements in group 1 have one valence electron.

The other exceptions to this trend are the transition metals, lanthanoids and actinoids, which have varying numbers of valence electrons. However, in general, metal elements have fewer than four valence electrons and non-metal elements have four or more valence electrons.

We can also determine the period an element is in using its electron configuration. For example, if an electron configuration contains two numbers (as for lithium, 2,1), then it has two shells of electrons and is in period 2.

Quick check 4.5

1. **Recall** the definition of valence electrons.
2. **Recall** how reactivity of an element is determined.
3. **State** the group that the element with the electron configuration 2,8 belongs to, and why.
4. **State** the period on the periodic table where the element with the electron configuration 2,8,4 is found.

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Excited electrons

When atoms absorb energy, with light or heat, for example, the valence electrons gain energy to move to higher energy electron shells. An electron that has jumped to a higher energy shell is said to be in an 'excited state', and when it releases energy to return to its 'ground state', that energy is released as a specific wavelength (colour) of light.

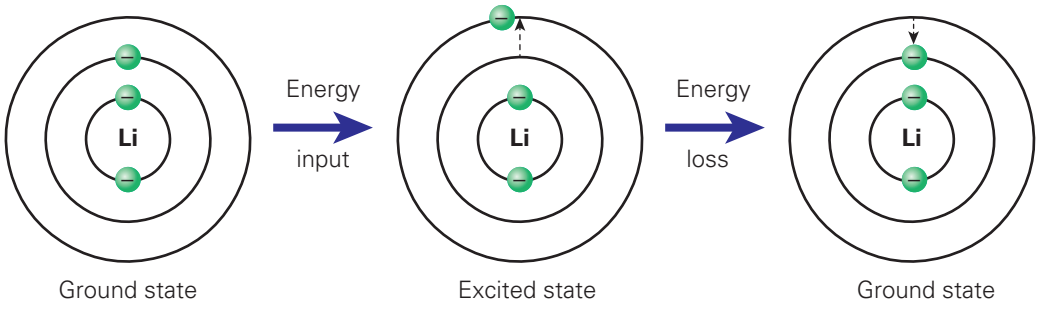

Figure 4.13 What happens to atoms when electrons gain energy?

The difference in energy between electron shells is unique for every element, so each different element emits a unique wavelength of light. This allows for a qualitative observation and inference of a particular element based on the colour of the light emission when the element is excited with light or heat. An example of this is a flame test, in which an element is placed in a flame. Often the atomic emission can be clearly visible, such as the green copper (Cu) and red lithium (Li) flames shown in Figure 4.14.

Figure 4.14 A copper compound burning with a green flame and a lithium compound burning with a red flame

Explore! 4.1

Niels Bohr and the atomic emission of hydrogen

A spectroscope is an instrument capable of separating white light into a continuous spectrum of visible wavelengths that resembles a rainbow. In 1913, the Danish scientist Niels Bohr used a spectroscope to view the continuous spectrum of light that had been absorbed and emitted by hydrogen. He observed that hydrogen absorbed very specific wavelengths of light (shown in its absorption spectrum) and emitted these exact wavelengths of light (emission spectrum).

Hydrogen is an atom with one electron, and Bohr theorised that the absorbed light energy was transferred to the electron, which moved to a higher energy state. As the electron released this amount of energy, as light, it returned to its original energy level. This is the same explanation used to describe the colours observed in a flame test above. In 1922, Niels Bohr was awarded the Nobel Prize for this work, which led him to propose an atomic model in which electrons orbited the nucleus in shells. The Bohr model of the atom is the electron shell model used in this chapter.

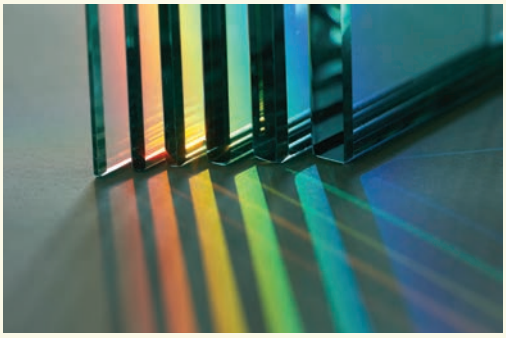

Figure 4.15 White light passes through glass and is split into a continuous (visible) spectrum.

continued …

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The pattern of lines on an emission spectrum correspond to a particular element. They are exactly like barcodes!

1. What are the main differences between an emission spectrum and an absorption spectrum, such as those shown in Figure 4.16?
2. Research which colour of light has the highest energy.
3. Deduce what element is present in the unknown emission spectrum shown in Figure 4.17.

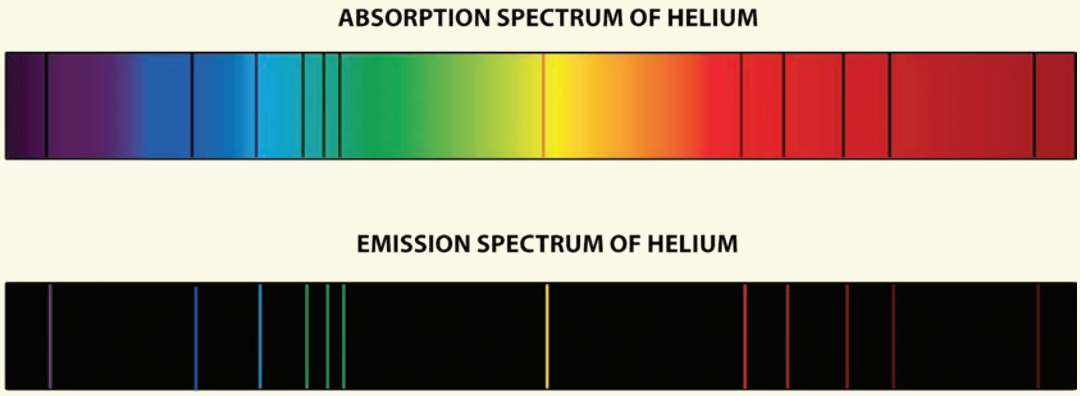

Figure 4.16 The absorption spectrum and emission spectrum of helium

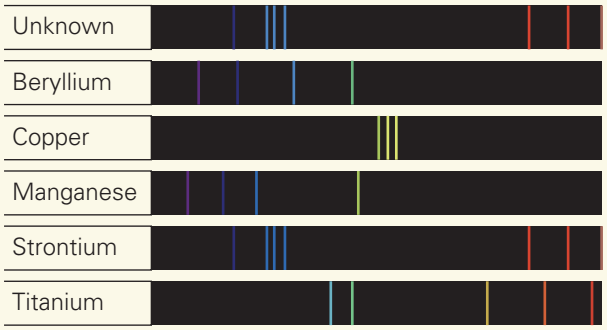

Figure 4.17 We can compare emission spectra to find out the identity of an unknown element.

Did you know? 4.1

Fireworks

Fireworks are an example of multiple flame tests occurring all at once in explosions in the sky! The colours observed are due to the absorption of energy and emission of light from various elements, including calcium (orange), strontium (red) and potassium (lilac).

Figure 4.18 Fireworks rely on the energy emitted from excited electrons returning to ground state.

Quick check 4.6

1. **Recall** what causes electrons to become excited and move to higher energy levels.
2. **State** the type of energy that is emitted when electrons return to ground state.
3. **Recall** how we can identify the type of element present when electrons are excited.

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Practical 4.1

Flame tests using metal salts

Be careful
Wear appropriate personal protective equipment.

Aim

To observe the flame colours of different salt solutions.

Materials

- solutions of copper(II) chloride, potassium chloride, sodium chloride, lithium chloride and strontium chloride
- beakers
- test tubes
- distilled water
- wooden splints
- Bunsen burner
- bench mat
- matches

Method

1. Copy the results table into your science book.
2. Prior to the lesson, thoroughly soak a supply of wooden splints in a beaker of distilled water.
3. Fill sets of test tubes up to half-full with the salt solutions and immerse one splint in each of the tubes.
4. Hold a soaked splint in a blue Bunsen flame to reveal the flame colour, being careful not to let the splint burn too vigorously.
5. Dispose of used splints in another beaker filled with water.

Results

Metal compound	Colour in flame
Copper(II) chloride	
Lithium chloride	
Strontium chloride	
Sodium chloride	
Potassium chloride	

Discussion

1. What provides the energy in this experiment for electrons to be excited to the next energy level?
2. Why is it better to use a roaring blue flame than a yellow safety flame to observe the colour of light emitted?
3. Explain why different colours of light were observed for compounds containing different metallic elements.

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Section 4.1 review

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Section 4.1 questions

Remembering

1. **Identify** the correct numbers to complete the following table:

Electron shell	Maximum number of electrons
First	
Second	
Third	
Fourth	

2. **Recall** why the shell closest to the nucleus fills with electrons first.
3. For each of the following electron configurations, **state** the:
   i) name of the element
   ii) number of valence electrons
   iii) period the element is in
   iv) group the element is in.
   a) 2,8,2 b) 1 c) 2,5 d) 2,8,8,2
4. **State** the electron configurations for the following elements.
   a) Helium (He) b) Beryllium (Be) c) Phosphorus (P) d) Potassium (K)

Understanding

5. The electron configuration of carbon is 2,4. **Draw** a diagram of a carbon atom with this electron configuration.
6. **Describe** the order in which electrons fill shells around the nucleus.

Applying

7. **Explain** why elements in the same group have similar properties.
8. Chlorine has the electron configuration 2,8,7. **Construct** a diagram that represents the arrangement of the electrons within a chlorine atom.
9. Use your knowledge of electron arrangement to **explain** what is significant about the electron configurations of group 18 elements.

Analysing

10. **Distinguish** between valence electrons and inner-shell electrons of an atom.
11. **Compare** the number of valence electrons of the metals sodium and magnesium to the non-metals oxygen and fluorine.

Evaluating

12. Helium, a group 18 element, has the electron configuration 2, meaning that it has two valence electrons. **Discuss** why helium is not located next to hydrogen with the other group 2 elements, which also have two valence electrons.
13. **Construct** a diagram which shows an example of what happens when electrons are excited from ground state in a hydrogen atom.
14. A student was instructed to conduct a flame test using copper(II) chloride and lithium chloride. **Discuss** the results they would obtain.

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4.2 Covalent bonding

Learning goals

At the end of this section, I will be able to:

1. Describe the covalent bonding model.
2. List the properties of covalently bonded substances.
3. Write the name and chemical formulas for covalent molecules.

WORKSHEET Covalent bonding

Atoms that do not have a full valence shell of electrons rarely exist as individual atoms, as atoms are in their most chemically stable state when their valence shell is full or they have achieved the octet rule. Atoms therefore tend to undergo chemical reactions which involve the transfer of valence electrons or sharing of valence electrons to achieve a full valence shell. Atoms which transfer or share valence electrons form very strong attractions to one another called **chemical bonds**.

chemical bond the association of two atoms due to the transfer of electrons between them or the sharing of valence electrons

bonding pair two valence electrons that are shared between two different atoms

covalent bond the formal sharing of a pair of valence electrons

diatomic a substance made up of two atoms bonded together

molecule elements and compounds containing two of more atoms combined with covalent bonds

Covalent bonds

Non-metal atoms tend to fill the valence shell by formally sharing valence electrons with other non-metal atoms such that both atoms can achieve the octet rule. Take a hydrogen atom as the simplest example; it has one proton in its nucleus and therefore one electron in its valence shell. To achieve a full valence shell, it requires two electrons as it is the first electron shell. A hydrogen atom can share the one valence electron with another hydrogen atom to create a **bonding pair** of electrons which are formally shared between the two atoms. That is to say that both hydrogen atoms have achieved a valence shell with two electrons, as they both 'feel' like they have two valence electrons.

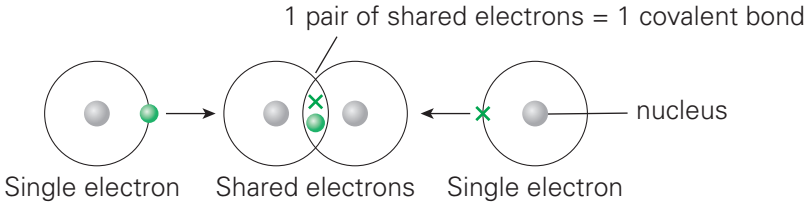

Figure 4.19 Sharing of electrons between non-metallic atoms in covalent compounds

This shared bonding pair of electrons is called a **covalent bond** and is the most common type of chemical bond between non-metal atoms. The hydrogen atoms combined in this example form a **diatomic** substance, H_2. The subscript '2' denotes that there are two atoms of hydrogen present in the covalently bonded substance. Elements and compounds that are combined in this way with covalent bonds are called **molecules**.

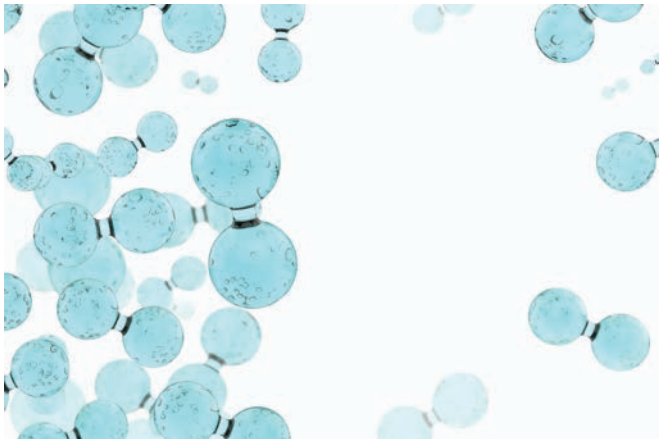

Figure 4.20 A visualisation of H_2 molecules.

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molecular element atoms of the same element chemically combined with covalent bonds

molecular compound atoms of different elements chemically combined with covalent bonds

There are many elements that are chemically bonded by covalent bonds, and these are called **molecular elements**. A list of common molecular elements is shown in Table 4.3. Molecular elements generally take the name of the element, though there are some unique examples such as ozone (O_3), when the element name has already been used to describe another molecular element.

Name	Formula
Oxygen	O_2
Ozone	O_3
Chlorine	$C\ell_2$
Bromine	Br_2
Fluorine	F_2
Iodine	I_2
Nitrogen	N_2
Sulfur	S_8

Table 4.3 Names and formulas of common molecular elements

Non-metal atoms of different elements can chemically combine to form compounds. When these compounds contain covalent bonds, they are called **molecular compounds**. Some molecular compounds have common names that need to be learned on their own without other naming rules. Some examples are provided below in Table 4.4.

Common name	Formula
Water	H_2O
Hydrogen peroxide	H_2O_2
Ammonia	NH_3
Methane	CH_4
Glucose	$C_6H_{12}O_6$

Table 4.4 The common names and formulas for some molecular compounds

Properties of covalent molecules

Covalent molecules are discrete in nature. That is, each molecule is its own entity and not connected to other molecules. Molecules are generally weakly attracted to each other as they are not chemically bonded, and so a relatively small amount of energy is required to overcome the attractions between molecules. The general properties of covalent molecular substances are described in Table 4.5.

Property	Explanation
Soft	A small amount of energy is required to break interactions between molecules.
Low melting point	A small amount of energy is required to break interactions between molecules.
Non-conductor of electricity or heat	Molecules have no mobile charge carriers available to transfer heat or current.

Table 4.5 Properties of covalent molecules

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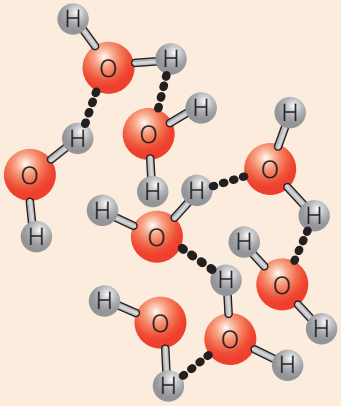
Did you know? 4.2

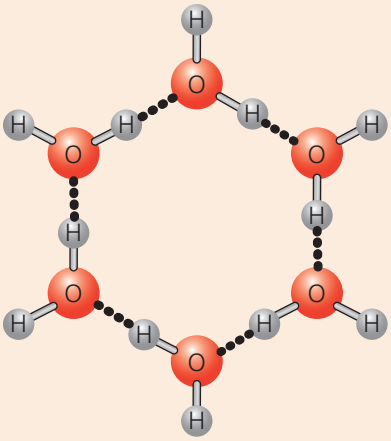
The unique properties of water

Water is a covalent molecule with a unique set of properties that make it extremely useful in our everyday lives. When liquids freeze to become solids, they usually contract, as you might have learned in year 7. But you might have noticed that frozen water, or ice, actually expands. This is why you shouldn't put a glass bottle of water in the freezer, as it will likely break when the ice expands!

In the liquid state, water molecules roll over each other in random motion. However, when water freezes, the molecules arrange themselves in a very regular arrangement, forming a lattice of hexagons with a large void in the middle. This regular arrangement takes up more volume, but also gives ice a symmetrical repeating lattice of water molecules. The regular pattern of molecules can be observed by the pretty patterns displayed by a snowflake.



Arrangement of molecules in water



Arrangement of molecules in ice

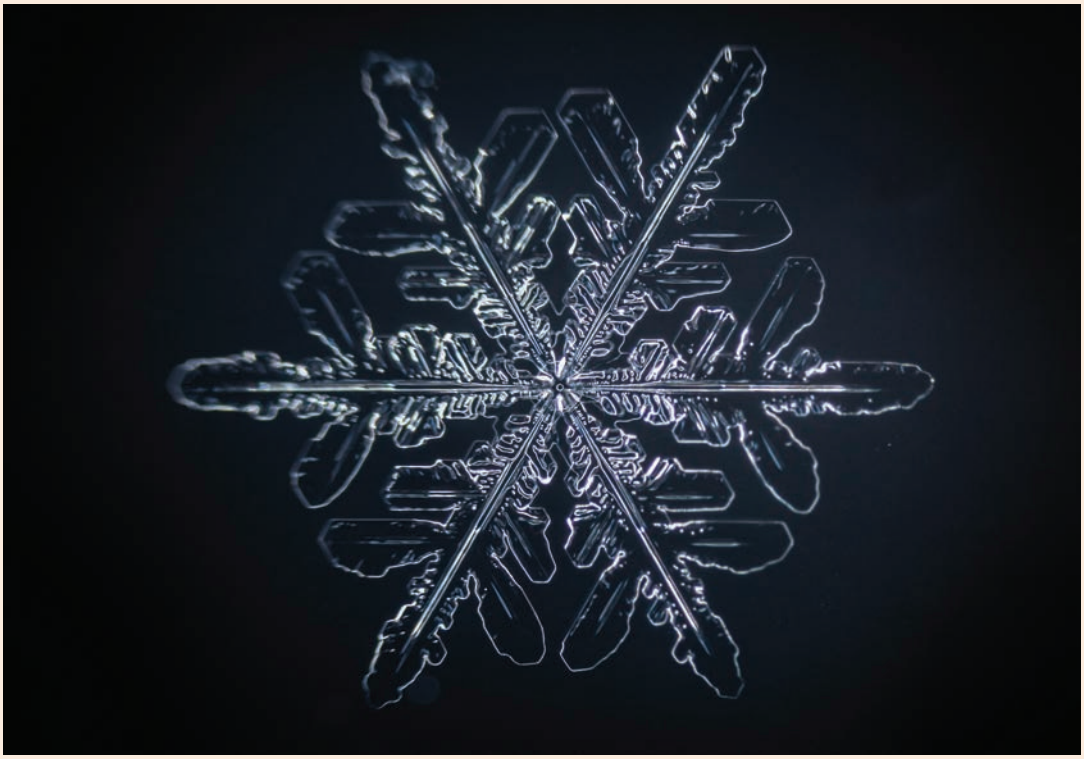


Figure 4.21 The regular arrangement of water molecules in a snowflake is observed as a pattern in the ice.

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Naming molecular compounds

molecular formula a symbol formula showing the number and type of each element covalently bonded together

While some molecular compounds have common names, there are some general rules that can be used to name substances of this type from a given chemical formula. When working with covalent molecules, the chemical formula can be referred to as the **molecular formula**. A molecular formula gives information on the number and type of each atom covalently bonded in each molecule. For example, the molecular formula CO_2 denotes a molecular compound made up of one carbon atom and two oxygen atoms.

In naming molecular compounds, some prefixes are used to describe the number of each type of atom in the molecule. These prefixes are shown in Table 4.6. Note that the prefix 'mono-' is only used if there is one atom in the second element in a molecular formula. If the first element has one atom, it is not given a prefix.

Number of atoms	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Table 4.6 Prefixes used for naming molecular compounds

Worked example 4.2

Naming molecular compounds

Name the molecules SO_3 and N_2O.

Working		Explanation
SO_3	N_2O	
sulfur oxygen	nitrogen oxygen	Identify the name of each element in the molecule.
sulfur trioxygen	dinitrogen monooxygen	Add the prefix to each element to denote the number of each type of atom.
sulfur trioxygen	dinitrogen monooxygen → monoxygen	If the element name starts with a vowel, remove the final letter of the prefix.
trioxygen → trioxide	monoxygen → monoxide	The second element takes the suffix of 'ide'.
Sulfur trioxide	Dinitrogen monoxide	Write the final name with a space between the two elements.

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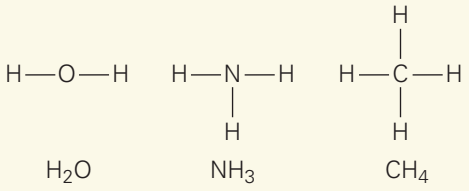
Quick check 4.7

1. **Write** the name for the following molecular compounds.
   a) SO_2
   b) P_4O_{10}
   c) NH_3
   d) CO

Explore! 4.2

Three-dimensional shapes of molecules

Covalent molecules can be described by their molecular formula, or the covalent bonds can even be drawn in two dimensions. Take a look at how the molecular compounds water (H_2O), ammonia (NH_3) and methane (CH_4) look in two dimensions in the diagram below. The lines between elements can be thought of as a covalent bond.



Covalent molecules actually exist as structures in three dimensions, though this can be difficult to imagine from a two-dimensional image.

1. Use the internet to visit the MolView app.
2. Draw these two-dimensional images and observe their structures in three dimensions.
3. Which of the following words would you use to describe their shapes?
   Bent, pyramidal, tetrahedral, trigonal planar, linear

Molecular compounds with more than two different elements have different naming rules that will not be covered here. In general, molecules should be named using their common name – for example, 'water' instead of 'dihydrogen monoxide' – but otherwise using the naming rules demonstrated in this section. Writing molecular formulas for covalent molecules from their names is rather straightforward, as the number of each element is provided.

For example, carbon disulfide, CS_2 describes a molecule with one carbon and two sulfur atoms.

Quick check 4.8

1. **Write** the molecular formula for the following molecular compounds.
   a) Nitrogen trifluoride
   b) Carbon tetrachloride
   c) Dichlorine monoxide
   d) Nitrogen dioxide

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Section 4.2 questions

Remembering

1. **List** three general properties of covalently bonded molecules.
2. **State** the common names of the following molecules.
   a) H_2O
   b) NH_3
   c) CH_4

Understanding

3. **Determine** the formulas for the following molecular elements.
   a) Oxygen
   b) Nitrogen
   c) Chlorine
   d) Ozone

Applying

4. **Determine** the formulas for the following molecular compounds.
   a) Dinitrogen tetroxide
   b) Carbon monoxide
   c) Tetraphosphorus pentoxide

Analysing

5. **Analyse** the following molecular formulas to determine the name of each of the following.
   a) SO_2
   b) NF_3
   c) Br_2S

Evaluating

6. Oxygen has a very low melting point of –218.8°C. **Explain** this property with reference to the type of bonding present in a molecule of oxygen.

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4.3 Ionic bonding

Learning goals

At the end of this section, I will be able to:

1. Describe the ionic bonding model.
2. List the properties of ionically bonded substances.
3. Write the name and chemical formula for ionic compounds.

WORKSHEET
Ionic bonding

Ions

The number of electrons and valence electrons of an atom of an element can be determined using the atomic number of the element. For example, an atom of sodium (Na) has 11 protons and therefore 11 electrons, with an electron configuration of 2,8,1. For the atom of sodium to have a full valence shell, either the one valence electron can be lost (with a resulting electron configuration of 2,8) or seven more electrons can be added to the valence shell (with a resulting electron configuration of 2,8,8). While both the loss and addition of electron(s) can occur, removing one electron needs far less energy than gaining seven electrons.

Thus, a sodium (Na) atom that has lost one electron has a full valence shell, though the atom now has 11 protons and 10 electrons, giving it an overall positive (+1) charge. An atom that has a formal positive or negative charge is called an **ion**. A positively charged ion, such as sodium, is called a **cation**, and is represented by showing the charge next to the element symbol – in this case, Na^+. If an atom loses more than one electron to achieve a full valence shell, this is shown as multiple charges next to the element symbol, for example, Mg^{2+} or $A\ell^{3+}$. Metal atoms, as well as hydrogen, tend to form cations.

ion
an atom with a formal positive or negative charge due to the loss or gain of electron(s)

cation
a positively charged ion

anion
a negatively charged ion

An atom that gains electrons to fill the valence shell becomes a negatively charged ion, also called an **anion**. For example, an atom of fluorine has nine protons and nine electrons with an electron configuration of 2,7 (see Figure 4.22). The atom can gain one more electron to fill the valence shell and become 2,8. The resulting anion would be represented by the symbol F^-. Non-metal atoms tend to form anions as they generally have more than four valence electrons.

The charge that atoms of elements tend to form can be predicted from the group numbers on the periodic table as shown in Figure 4.23. Group 14 elements tend not to form ions due to the large amount of energy required to either lose or gain four electrons. Moreover, the group 18 noble gases already have a full valence shell and do not form ions.

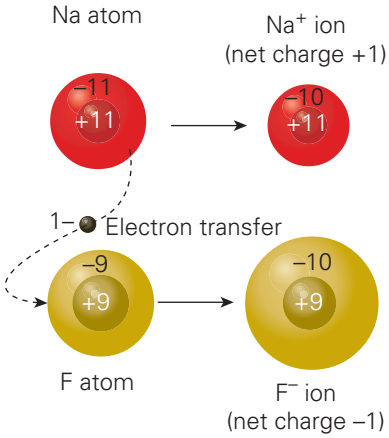

Figure 4.22 A positively charged ion (a cation) bonds with a negatively charged ion (an anion) through the loss and addition of electrons.

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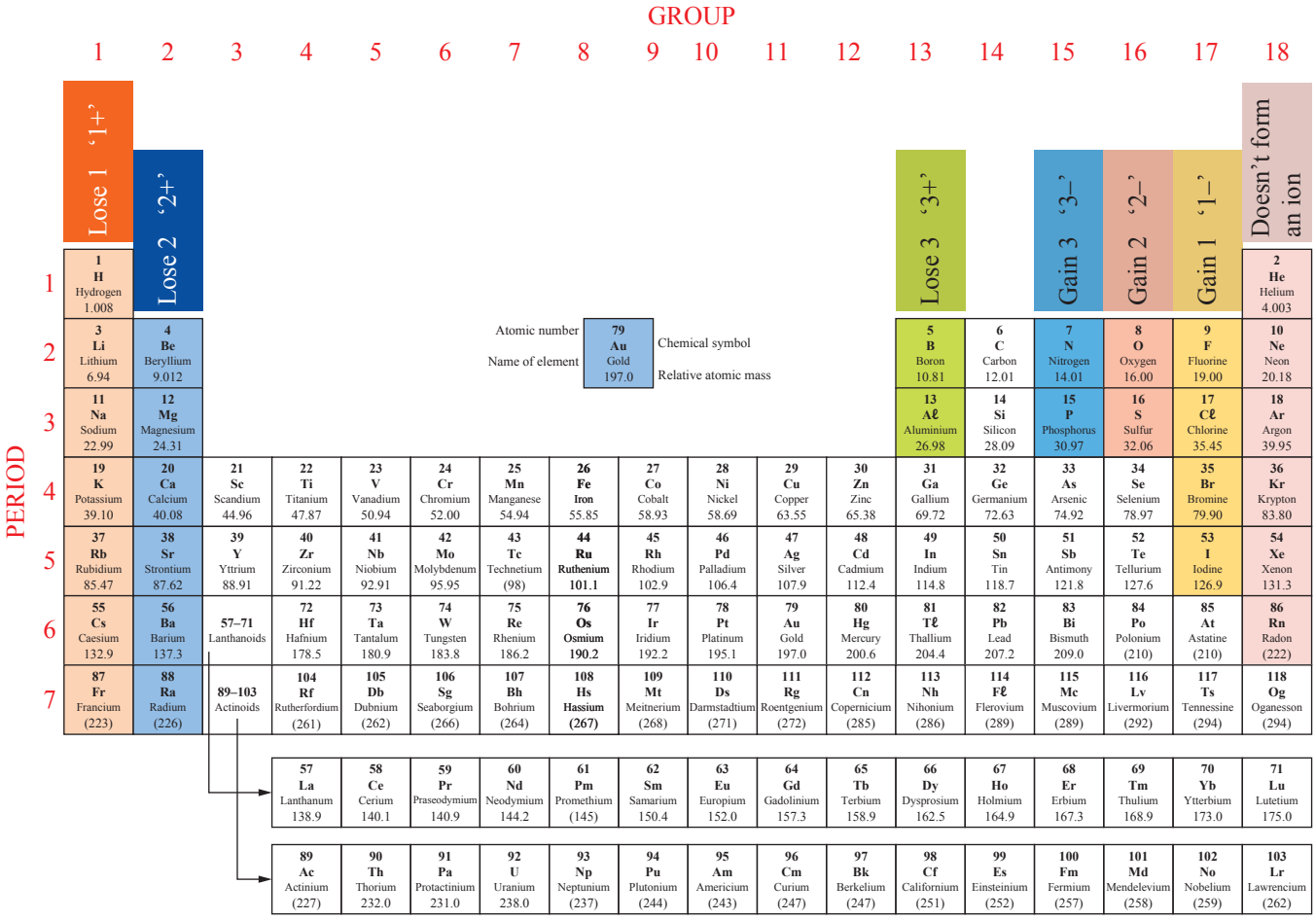
GROUP
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Lose 1 '1+'
Lose 2 '2+'
Lose 3 '3+'
Gain 3 '3–'
Gain 2 '2–'
Gain 1 '1–'
Doesn't form an ion
PERIOD
1 2 3 4 5 6 7
Atomic number
Name of element
79 Au Gold 197.0
Chemical symbol
Relative atomic mass
1 H Hydrogen 1.008
2 He Helium 4.003
3 Li Lithium 6.94
4 Be Beryllium 9.012
5 B Boron 10.81
6 C Carbon 12.01
7 N Nitrogen 14.01
8 O Oxygen 16.00
9 F Fluorine 19.00
10 Ne Neon 20.18
11 Na Sodium 22.99
12 Mg Magnesium 24.31
13 Aℓ Aluminium 26.98
14 Si Silicon 28.09
15 P Phosphorus 30.97
16 S Sulfur 32.06
17 Cℓ Chlorine 35.45
18 Ar Argon 39.95
19 K Potassium 39.10
20 Ca Calcium 40.08
21 Sc Scandium 44.96
22 Ti Titanium 47.87
23 V Vanadium 50.94
24 Cr Chromium 52.00
25 Mn Manganese 54.94
26 Fe Iron 55.85
27 Co Cobalt 58.93
28 Ni Nickel 58.69
29 Cu Copper 63.55
30 Zn Zinc 65.38
31 Ga Gallium 69.72
32 Ge Germanium 72.63
33 As Arsenic 74.92
34 Se Selenium 78.97
35 Br Bromine 79.90
36 Kr Krypton 83.80
37 Rb Rubidium 85.47
38 Sr Strontium 87.62
39 Y Yttrium 88.91
40 Zr Zirconium 91.22
41 Nb Niobium 92.91
42 Mo Molybdenum 95.95
43 Tc Technetium (98)
44 Ru Ruthenium 101.1
45 Rh Rhodium 102.9
46 Pd Palladium 106.4
47 Ag Silver 107.9
48 Cd Cadmium 112.4
49 In Indium 114.8
50 Sn Tin 118.7
51 Sb Antimony 121.8
52 Te Tellurium 127.6
53 I Iodine 126.9
54 Xe Xenon 131.3
55 Cs Caesium 132.9
56 Ba Barium 137.3
57–71 Lanthanoids
72 Hf Hafnium 178.5
73 Ta Tantalum 180.9
74 W Tungsten 183.8
75 Re Rhenium 186.2
76 Os Osmium 190.2
77 Ir Iridium 192.2
78 Pt Platinum 195.1
79 Au Gold 197.0
80 Hg Mercury 200.6
81 Tℓ Thallium 204.4
82 Pb Lead 207.2
83 Bi Bismuth 209.0
84 Po Polonium (210)
85 At Astatine (210)
86 Rn Radon (222)
87 Fr Francium (223)
88 Ra Radium (226)
89–103 Actinoids
104 Rf Rutherfordium (261)
105 Db Dubnium (262)
106 Sg Seaborgium (266)
107 Bh Bohrium (264)
108 Hs Hassium (267)
109 Mt Meitnerium (268)
110 Ds Darmstadtium (271)
111 Rg Roentgenium (272)
112 Cn Copernicium (285)
113 Nh Nihonium (286)
114 Fℓ Flerovium (289)
115 Mc Muscovium (289)
116 Lv Livermorium (292)
117 Ts Tennessine (294)
118 Og Oganesson (294)
57 La Lanthanum 138.9
58 Ce Cerium 140.1
59 Pr Praseodymium 140.9
60 Nd Neodymium 144.2
61 Pm Promethium (145)
62 Sm Samarium 150.4
63 Eu Europium 152.0
64 Gd Gadolinium 157.3
65 Tb Terbium 158.9
66 Dy Dysprosium 162.5
67 Ho Holmium 164.9
68 Er Erbium 167.3
69 Tm Thulium 168.9
70 Yb Ytterbium 173.0
71 Lu Lutetium 175.0
89 Ac Actinium (227)
90 Th Thorium 232.0
91 Pa Protactinium 231.0
92 U Uranium 238.0
93 Np Neptunium (237)
94 Pu Plutonium (244)
95 Am Americium (243)
96 Cm Curium (247)
97 Bk Berkelium (247)
98 Cf Californium (251)
99 Es Einsteinium (252)
100 Fm Fermium (257)
101 Md Mendelevium (258)
102 No Nobelium (259)
103 Lr Lawrencium (262)

Figure 4.23 Periodic table indicating the main group elements and the charges of the ions formed by these elements' atoms when they lose or gain electrons. Note that groups 14 and 18 typically do not form ions.

The metal elements that are not shaded on the periodic table tend to form many different cation charges. It is generally not necessary to memorise these charges because they are given in the name of the element as roman numerals. For example, the name copper(II) tells us that it is the Cu^{2+} ion. In some cases, metals can lose up to seven electrons, such as manganese(VII), Mn^{7+},. Therefore, it is important that you can recognise the first seven roman numerals. However, two transition metals that should be memorised are silver, Ag^{+}, and zinc, Zn^{2+}, as roman numerals are not used to describe these ions.

Explore! 4.3

Roman numerals

Use your preferred search engine to research the rules for counting in roman numerals. Use your findings to identify the number shown in Figure 4.24.

Figure 4.24 Roman numerals on a sign

Quick check 4.9

1. **Write** the electron configuration for the following ions.

a) Li^{+} **b)** O^{2-} **c)** Scandium(I) **d)** Aluminium(III)

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Polyatomic ions

In some cases, a covalent molecule forms with an overall charge, thus forming an ion with more than one atom covalently bonded together. This is called a **polyatomic ion**. In fact, polyatomic ions are any ions that contain more than one atom in their formation. For example, the ammonium ion has the formula NH_4^+. It is a covalent molecule made up of a nitrogen atom and four hydrogen atoms, but overall, it has a positive charge and is a cation.

In this chapter, it is not important to know which atom has lost or gained the electron in the polyatomic ion, but just that they exist. The list of common polyatomic ion formulas and names used in this course are shown in Table 4.7.

polyatomic ion
a covalent molecule with an overall charge

electrostatic attraction
the force of attraction between positively and negatively charged particles

ionic bond
the transfer of valence electrons from one atom to another, resulting in an electrostatic attraction between ions

lattice
a three-dimensional structure in which atoms/ions are in fixed positions

crystalline
a perfect lattice structure without deformities

Name	Formula	Name	Formula
Ammonium	NH_4^+	Hydrogencarbonate	HCO_3^-
Hydroxide	OH^-	Sulfate	SO_4^{2-}
Nitrate	NO_3^-	Carbonate	CO_3^{2-}
Ethanoate (acetate)	CH_3COO^-	Phosphate	PO_4^{3-}

Table 4.7 List of names and formulas of common polyatomic ions

The ionic bonding model

When ions form, the electrons are transferred from one atom to another to create a cation and an anion simultaneously; that is, a cation cannot form without an anion forming at the same time. For example, when a sodium atom forms a sodium ion, the electron must be gained by another atom, such as chlorine, to form an anion. The positive charge of a cation interacts with the negative charge of an anion to form a strong **electrostatic attraction**. This attraction between positive and negative ions is called an **ionic bond** and is a result of a transfer of a valence electron or multiple valence electrons from one atom to another. As metal elements generally form cations, and non-metal elements generally form anions, ionic bonds are a common type of chemical bond between metals and non-metals. Therefore, ionic compounds are generally made up of both metals and non-metals.

Ionic compounds are not discrete molecules like covalent compounds. Instead, the ions form a three-dimensional **lattice** structure of alternating cations and anions held together by strong electrostatic attractions, or ionic bonds. The lattice structure shown between sodium and chlorine ions in Figure 4.25 forms repeating cubic units; however, the ionic lattice can also form different-shaped units between alternating ions. When perfect lattices are formed, these substances are called **crystalline** and, to the naked eye, they look like crystals.

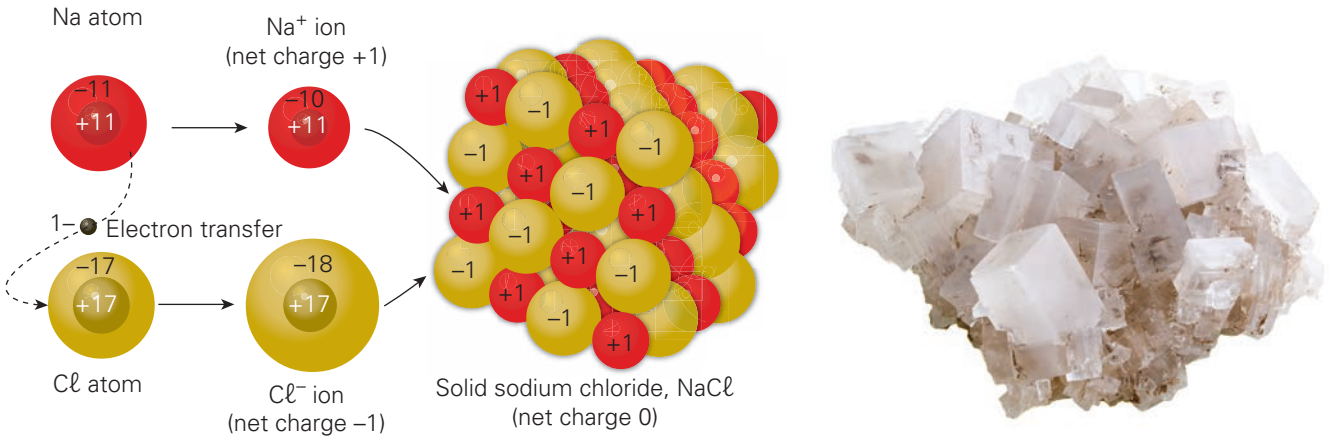

Figure 4.25 Cubic crystals of sodium chloride in rock salt

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Practical 4.2

Growing crystals of copper(II) sulfate and potassium aluminium sulfate (alum)

Aim

To grow crystalline ionic lattices of copper(II) sulfate and potassium aluminium sulfate (alum).

Materials

- any hydrated copper(II) sulfate solid (such as copper(II) sulfate pentahydrate)
- potassium aluminium sulfate (alum) solid
- distilled water
- 100 mL beakers
- stirring rod
- hotplate or Bunsen burner
- Petri dishes
- filter paper
- glass funnel

Method

1. Add 50 mL of distilled water to a 100 mL beaker and heat it gently over a heating source. (Note: The water should not boil.)
2. Add small amounts of hydrated copper(II) sulfate powder to the beaker while stirring with a stirring rod, until no more solid dissolves in the hot solution.
3. Filter the solution through a funnel fitted with filter paper.
4. Pour the resulting filtrate solution into smaller Petri dishes and leave them undisturbed to cool for several days. Note: It is important to not agitate the solution at this stage to grow the largest crystals.
5. Repeat the procedure using alum.
6. After a few days, record the size and shape of the crystals formed.

Results

In your science book, record the relative colour, size and shape of the copper(II) sulfate and alum crystals.

Discussion

Use the internet to research how you could optimise this procedure to produce larger crystals. List three changes you would make to your experiment to grow larger crystals.

Properties of ionic compounds

To break ionic bonds, a large amount of energy is required to overcome the electrostatic attraction between the cations and anions throughout the entire crystal lattice. Table 4.8 provides a brief description of some common properties of ionic compounds with respect to the ionic bonding model.

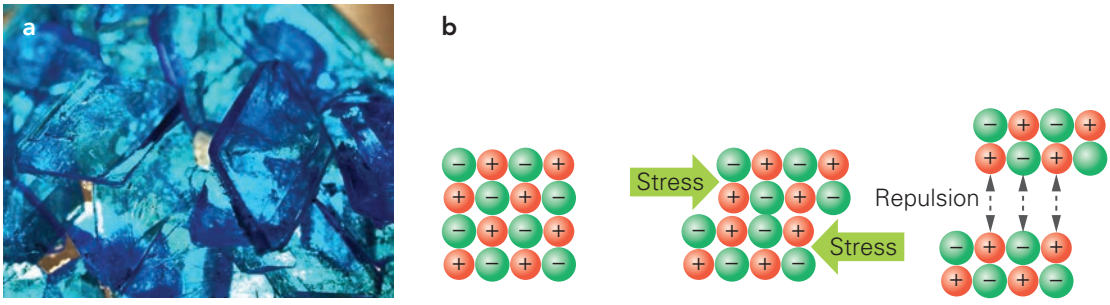

Figure 4.26 Copper(II) sulfate crystals are hard and non-conductive **(a)**, but when hit with a hammer they break into many smaller pieces due to repulsion of like-charged ions **(b)**.

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Property	Explanation
Hard	A large amount of energy is required to break ionic bonds throughout the three-dimensional lattice.
High melting point	A large amount of energy is required to break ionic bonds throughout the three-dimensional lattice.
Brittle	When force is applied to a crystal, ions with similar charges are pushed closer together and repel, fracturing the three-dimensional lattice.
Non-conductor of electricity or heat in the solid state	Ions are in fixed positions in the three-dimensional lattice, and there are no mobile charge carriers.

Table 4.8 Common properties of ionic compounds

Names of ionic compounds

The names and formulas for ionic compounds follow their own unique rules. It is important that you can interpret and write these on your own as it is a key skill required to be able to write chemical equations in Chapter 5.

Before following these rules for naming and writing formulas, which are described in Table 4.9, you must first identify that the compound is actually an ionic compound! The most effective way to do this is to identify whether a metal and a non-metal element are present, as these will almost always form an ionic compound. Moreover, if you observe a common polyatomic ion, such as nitrate (NO_3^-), for example, the compound is likely ionic. Finally, an ammonium ion (NH_4^+) can form ionic compounds without any metal elements being present.

The rules for naming ionic compounds are listed in Table 4.9.

Step	Explanation	Example
1	The name of the cation is placed first in the name, and it is the same as the name of the element or polyatomic ion.	Sodium (Na^+) Magnesium (Mg^{2+}) Ammonium (NH_4^+)
2	If the cation is a transition metal, lanthanoid or actinoid, the charge of the ion should be given in roman numerals directly after the element name.	Copper(I) (Cu^+) Lead(II) (Pb^{2+}) Europium(III) (Eu^{3+}) Uranium(IV) (U^{4+})
3	The name of the anion is placed second. The suffix of the element is changed to '-ide'. If the anion is a polyatomic ion, then the whole name of the polyatomic ion is used.	Fluor~~ine~~ → fluoride (F^-) Ox~~ygen~~ → oxide (O^{2-}) Nitr~~ogen~~ → nitride (N^{3-}) Nitrate (NO_3^-)
4	The cation and anion names are placed in order with a space in between them.	Sodium chloride Lead(II) oxide Europium(III) nitrate

Table 4.9 Rules for naming ionic compounds

Unlike the naming of covalent molecules, the number of each element is not relevant in the name. So, prefixes such as mono-, di- and tri- are never used in the names of ionic compounds.

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Quick check 4.10

1. **Write** the names of the following ionic compounds from their formulas.
   a) LiBr
   b) FeS
   c) $A\ell(OH)_3$
   d) Mg_3N_2

Formulas of ionic compounds

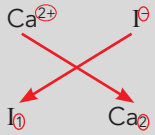
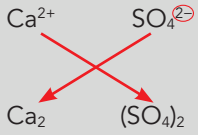
As ionic compounds make up a three-dimensional lattice, there are often millions of ions present in the crystalline structure. Identifying the exact number of each ion present in a substance would be too challenging, and so the chemical formula of ionic compounds is shown as the simplest whole-number ratio of cations and anions in the ionic lattice. Take, for example, the formula of sodium chloride, $NaC\ell$. This formula describes the ionic lattice as having one Na^+ cation for every one $C\ell^-$ anion; whereas in $MgC\ell_2$, there is one Mg^{2+} cation for every two $C\ell^-$ ions. This notation can be described as showing one unit of the ionic lattice.

In an ionic lattice, the overall charge must be zero, so ion charges should be cancelled in the chemical formula of an ionic compound. This is the reason why a Mg^{2+} ion requires two $C\ell^-$ ions to balance the charge. Some combinations of ions are trickier to evaluate, and so a 'drop and swap' method for writing a formula can be followed to help write more challenging examples.

Worked example 4.3

Writing the formula for ionic compounds 1

Write the formulas for calcium iodide and calcium sulfate.

Working		Explanation
Calcium iodide	**Calcium sulfate**	
Ca^{2+}, as it is a group 2 metal	Ca^{2+}, as it is a group 2 metal	Write the symbol of the elemental ion or polyatomic ion present in the compound.
I^-, as it is a group 17 non-metal	SO_4^{2-} is a known polyatomic ion	
$Ca^{2+}\ I^-$ $Ca_1\ I_2$ 	$Ca^{2+}\ SO_4^{2-}$ $Ca_2\ (SO_4)_2$ 	The superscript coefficients are 'dropped and swapped' and the charge signs removed. Polyatomic ions are placed inside brackets before dropping the coefficients.
Already in simplest form $Ca_1\ I_2$	$Ca_2\ (SO_4)_2$ $Ca_1\ (SO_4)_1$	Simplify to the lowest whole-number ratio.
CaI_2	$CaSO_4$	Combine the elements and remove any coefficients of 1. Polyatomic ions with a coefficient of 1 can be removed from inside brackets.

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Quick check 4.11

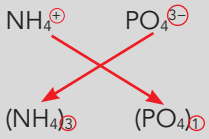
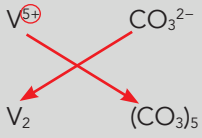
1. **Write** the formulas for the following ionic compounds from their names.
   a) Iron(II) sulfide
   b) Lithium oxide
   c) Zinc hydroxide
   d) Copper(I) carbonate

The 'drop-and-swap' method can also be used for the trickiest examples that include many polyatomic ions or higher cation charges.

Worked example 4.4

Writing the formula for ionic compounds 2

Write the formulas for ammonium phosphate and vanadium(V) carbonate.

Working		Explanation
Ammonium phosphate	**Vanadium(V) carbonate**	
NH_4^+ is a known polyatomic ion PO_4^{3-} is a known polyatomic ion	V^{5+}, given the roman numeral V CO_3^{2-}, is a known polyatomic ion	Write the symbol of the elemental ion or polyatomic ion present in the compound.
NH_4^+ PO_4^{3-} $(NH_4)_3$ $(PO_4)_1$ 	V^{5+} CO_3^{2-} V_2 $(CO_3)_5$ 	The superscript coefficients are 'dropped and swapped' and the charge signs removed. Polyatomic ions are placed inside brackets before dropping the coefficients.
Already in simplest form $(NH_4)_3$ $(PO_4)_1$	Already in simplest form V_2 $(CO_3)_5$	Simplify to the lowest whole-number ratio.
$(NH_4)_3PO_4$	$V_2(CO_3)_5$	Combine the elements and remove any coefficients of 1. Polyatomic ions with a coefficient of 1 can be removed from inside brackets.

Quick check 4.12

1. **Write** the formulas for the following ionic compounds from their names.
   a) Ammonium ethanoate
   b) Aluminium phosphate
   c) Manganese(VII) chloride
   d) Lead(IV) oxide

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Section 4.3 questions

Remembering

1. **State** the difference between cations and anions.
2. **Recall** the symbol formula for the following ions.
   a) Sodium
   b) Aluminium
   c) Hydroxide
   d) Phosphate
   e) Oxide
3. **Recall** the electron configuration for the following ions.
   a) K^+
   b) $C\ell^-$
   c) N^{3-}
   d) Sc^+

Understanding

4. Using $NaC\ell$ as an example, **describe** the ionic bonding model.
5. **Determine** the names of the following ionic compounds.
   a) NaBr
   b) CaS
   c) $A\ell H_3$
   d) Li_2O

Applying

6. **Determine** the formula for the following ionic compounds.
   a) Magnesium nitride
   b) Iron(III) iodide
   c) Nickel(II) nitrate
   d) Tin(IV) oxide
   e) Potassium carbonate

Analysing

7. **Analyse** the following ionic compound formulas and write the correct names.
   a) Rb_2SO_4
   b) $ScCH_3COO$
   c) $Mn(HCO_3)_2$
   d) $(NH_4)_3PO_4$
   e) $V(OH)_5$

Evaluating

8. Potassium iodide is a brittle solid that does not conduct electricity in the solid state.
   Explain these properties with reference to the type of bonding present in potassium iodide.

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4.4 Metallic bonds

Learning goals

At the end of this section, I will be able to:

1. Describe the metallic bonding model.
2. List the properties of metallically bonded substances.
3. Write the name and chemical formulas for metallic substances.

WORKSHEET Metallic bonding

In the previous sections of this chapter, we have seen how non-metal atoms share valence electrons with each other to create covalent bonds and how metal atoms transfer electrons to non-metal atoms to create ionic bonds. In this section, we will look at how metal atoms are able to form chemical bonds together.

delocalised electron an electron that has become delocalised from an individual atom

metallic bond the electrostatic attraction between a lattice of metal cations and a 'sea' of delocalised electrons

The metallic bonding model

Metal atoms are prone to donating their valence electrons, as was the case in the ionic bonding model. However, other metal atoms do not easily accept valence electrons to fill the valence shell. Thus, metal atoms chemically bond in a different way.

In metals, atoms are organised in a three-dimensional lattice like in the ionic bonding model. The difference in this model is that all metal atoms lose their valence electrons to achieve the octet rule. That means that all of the metal atoms in the lattice have become cations. But where do the electrons go? In fact, they become delocalised in the lattice. **Delocalised electrons** are able to move freely throughout the three-dimensional lattice of cations to balance the charge of the lattice without belonging to any single ion.

The negatively charged delocalised electrons are electrostatically attracted to each of the cations that are in proximity, and these interactions are called **metallic bonds**. The metallic bonding model is therefore a lattice of metal cations in a 'sea' of delocalised electrons.

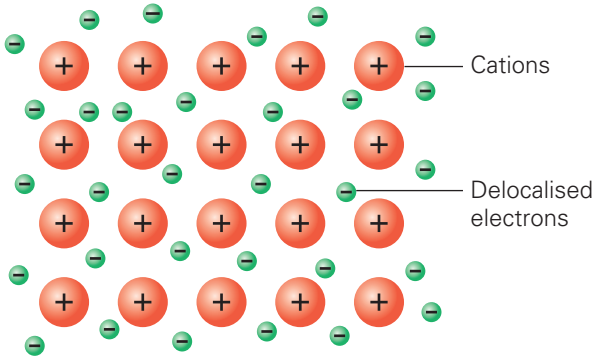

Figure 4.27 Metallic bonding occurs by having a 'sea' of delocalised electrons moving among positively charged metal ions (cations). This diagram shows just one layer of metal ions.

This is the type of bonding in all pure metals, such as copper, iron, silver and gold. Generally, metal ions release all of their valence electrons to achieve a stable valence shell. For example, metallic sodium would have a lattice of Na^+ ions, while metallic magnesium would have a lattice of Mg^{2+} ions.

malleable able to be hammered into sheets

ductile able to be drawn into a wire

Properties of metals

The unique bonding model in metals gives rise to a unique set of properties that make metals useful. A description of the general properties is given in Table 4.10.

Property	Explanation
Lustrous	Delocalised electrons reflect light waves that hit the surface of the metal.
Hard	A large amount of energy is required to overcome the metallic bonds.
High melting point	A large amount of energy is required to overcome the metallic bonds.
Malleable and **ductile**	When force is applied to a metallic lattice, cations can move over one another because they are stabilised by delocalised electrons.
Conductor of electricity or heat in solid state	Delocalised electrons can conduct heat and current through the lattice.

Table 4.10 General properties of metallically bonded substances

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Metal names and chemical formula

Pure metals have the simplest naming conventions of all the substances discussed in this chapter because metals take the name and symbol of their element. For example, pure gold has the name gold and the symbol Au. It does not matter that there are millions of gold atoms in a piece of gold, as they are all the same, so only one is shown in the formula. Moreover, it doesn't matter that the lattice is made up of Au^{3+} ions in a 'sea' of delocalised electrons as the overall charge is balanced, so the formula is Au. There are no tricks when it comes to metals!

However, metallic lattices can have some impurities when different metals are mixed together. These types of metallic lattices are not called compounds, but instead they are mixtures of metals called alloys. Alloys have very particular names depending on the metallic mixture present. Some examples are shown in Figures 4.28–4.32.

Figure 4.28 Brass is an alloy predominantly made up of copper (Cu) and zinc (Zn).

Figure 4.29 Bronze is an alloy predominantly made up of copper (Cu) and tin (Sn).

Figure 4.30 Sterling silver is an alloy predominantly made up of silver (Ag) and copper (Cu).

Figure 4.31 Nichrome is an alloy predominantly made up of nickel (Ni) and chromium (Cr).

Figure 4.32 Stainless steel is an alloy predominantly made up of iron (Fe), chromium (Cr), nickel (Ni) and molybdenum (Mo).

Quick check 4.13

1. **Write** the name for the following metals from their formulas.
   - **a)** K
   - **b)** Ag
   - **c)** Mn
   - **d)** Cr

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Explore! 4.4

Melting points in the periodic table

Now that you have covered the three types of bonding models, can you identify trends in melting points in the periodic table?

Analyse Figure 4.33 below.

1. What trends can be identified in the melting points?
2. Are there any anomalies in your observed trend?
3. What can you deduce about the elements in the periodic table from your answers to Questions 1 and 2?

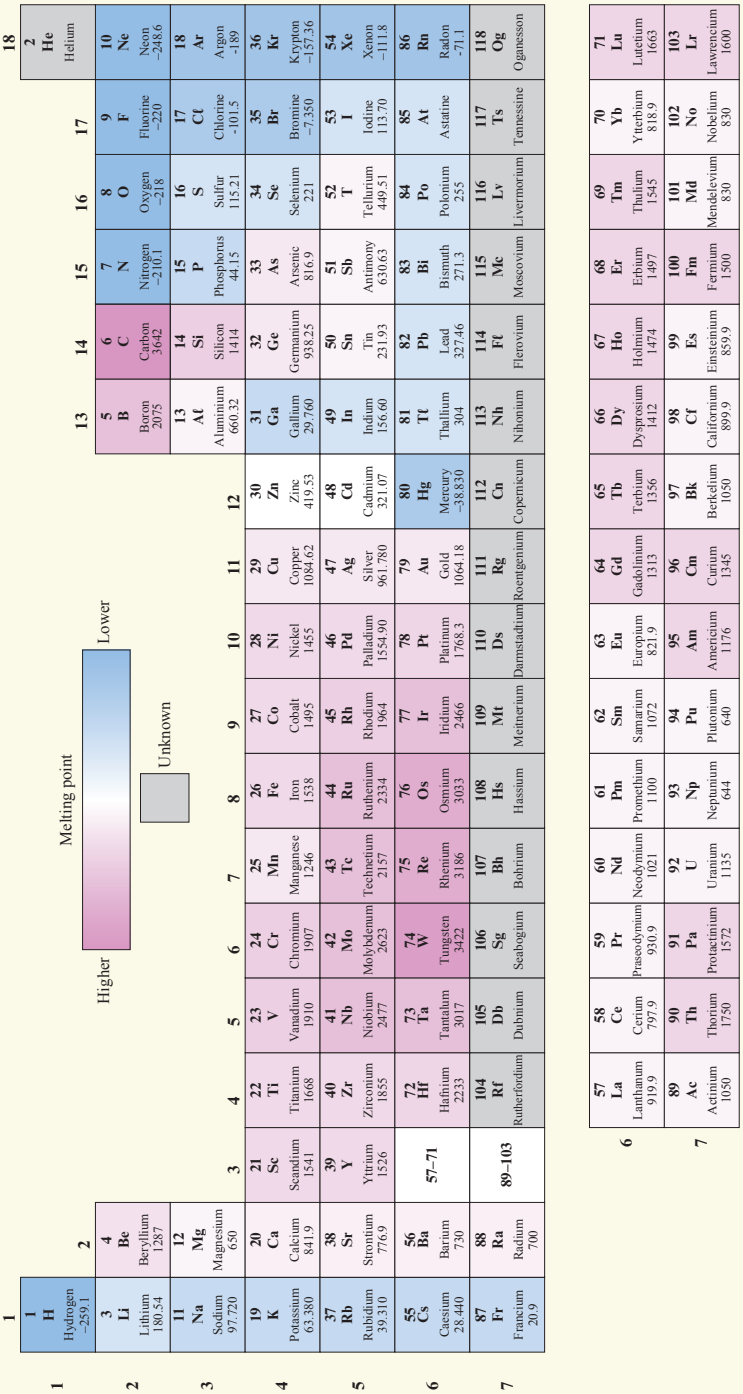

Figure 4.33 In this figure, melting points are listed in place of the relative atomic mass. Is there a trend in melting points in the periodic table?

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In this chapter, we have covered three types of chemical bonding. The three types of bonds are summarised in Table 4.11.

	Covalent	Ionic	Metallic
Types of elements	Usually non-metals	Usually a non-metal and a metal	Metals
Bonding model	Sharing of a bonding pair of electrons	Transfer of valence electrons to form a cation and an anion	A lattice of cations in a sea of delocalised electrons
Properties	• Soft • Low melting point • Non-conductive	• Hard • High melting point • Non-conductive in the solid state	• Hard • High melting point • Conductive • Lustrous
Name example	Carbon dioxide	Potassium oxide	Sodium
Formula example	CO_2	K_2O	Na

Table 4.11 A comparison summary of the three types of chemical bonding

Go online to access the interactive section review and more!

Section 4.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 4.4 questions

Remembering

1. **State** the formula for the following metals.
   a) Copper
   b) Gold
   c) Silver
   d) Platinum
2. **Identify** two metals in the following alloys.
   a) Brass
   b) Nichrome
   c) Bronze

Understanding

3. **Define** the metallic bonding model.

Applying

4. **Explain** why a sheet of aluminium has a 'shiny' surface.

Analysing

5. Copper metal can be drawn into wires for electrical applications. Name and **explain** this property of copper.

Evaluating

6. An unknown chemical substance does not conduct heat well in the solid state and is dull and brittle. The substance is known to contain the element calcium. **Evaluate** a possible chemical formula of this substance. (Note: There are multiple possible answers.)

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Chapter review

Chapter checklist

Success criteria		Linked questions
4.1	I can identify metals, non-metals and metalloids by their position on the periodic table.	1, 5
4.1	I can write the electron configuration for atoms and ions up to 20 electrons.	3
4.2	I can describe the covalent bonding model.	7, 13
4.2	I can list the properties of covalently bonded substances.	4a
4.2	I can write the name and chemical formulas for covalent molecules.	8, 9
4.3	I can describe the ionic bonding model.	6
4.3	I can list the properties of ionically bonded substances.	4b
4.3	I can write the name and chemical formulas for ionic compounds.	2, 7, 8, 9, 10
4.4	I can describe the metallic bonding model.	6
4.4	I can list the properties of metallically bonded substances.	4c
4.4	I can write the name and chemical formulas for metallic substances.	1, 8

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review

Review questions

Remembering

1. **Name** the following metallic substances.
   a) Sr
   b) Re
   c) Eu
   d) Pb
   e) Zn
2. **Name** the following polyatomic ions.
   a) CH_3COO^-
   b) SO_4^{2-}
   c) CO_3^{2-}
   d) NO_3^-
   e) NH_4^+
3. **State** the electron configuration for the following.
   a) Ca^{2+}
   b) C
   c) S^{2-}

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4. **List** three properties of substances that are formed from each the following types of bonds.
   a) covalent
   b) ionic
   c) metallic

Understanding

5. **Identify** the metals from the following list of elements: H, Na, Mg, W, Ge, Si, Cℓ, Ne.
6. **Distinguish** the metallic and ionic bonding models.
7. **Determine** the chemical formula for the following covalent molecules.
   a) Phosphorus triiodide
   b) Sulfur
   c) Hydrogen
   d) Nitrogen monoxide

Applying

8. **Determine** the names of the following compounds.
   a) $Cr(OH)_3$
   b) CO_2
   c) Cu_2O
   d) $LiNO_3$
   e) NH_4F
   f) $CC\ell_4$
9. **Determine** the formulas of the following compounds.
   a) Triphosphorus octoxide
   b) Beryllium sulfide
   c) Silver carbonate
   d) Water
   e) Methane
10. **Contrast** the naming rules for the compounds CO and CuO.

Analysing

11. Metallic and ionic substances generally have higher melting points than covalent substances. **Explain** this property with reference to models of bonding.
12. Silver metal is used in some electrical applications due to its good electrical conductivity. **Explain** why silver is conductive.

Evaluating

13. Methane does not conduct heat or electricity. **Explain** this property of methane with reference to the relevant model of bonding.
14. A white solid in an unlabelled jar is known to be either sodium chloride or glucose. The physical properties of the powder were tested, and the results were recorded below:
    - It is a non-conductor of electricity.
    - It dissolves readily in water.
    - Crystals of the solid shatter when force is applied.
    - The melting point is considered high at 801°C.

    Evaluate the information to identify the unknown solid.

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Data questions

Magnesium and calcium are group 2 alkaline earth metals and can be taken as general health supplements to aid regulation of bodily functions, including muscle functions and bone development. A scientist is testing the claim from eight different supplement brands that their magnesium and calcium tablets contain 200 mg of each element. Each supplement was analysed, and the amounts of magnesium and calcium present in each tablet are presented in Figure 4.34.

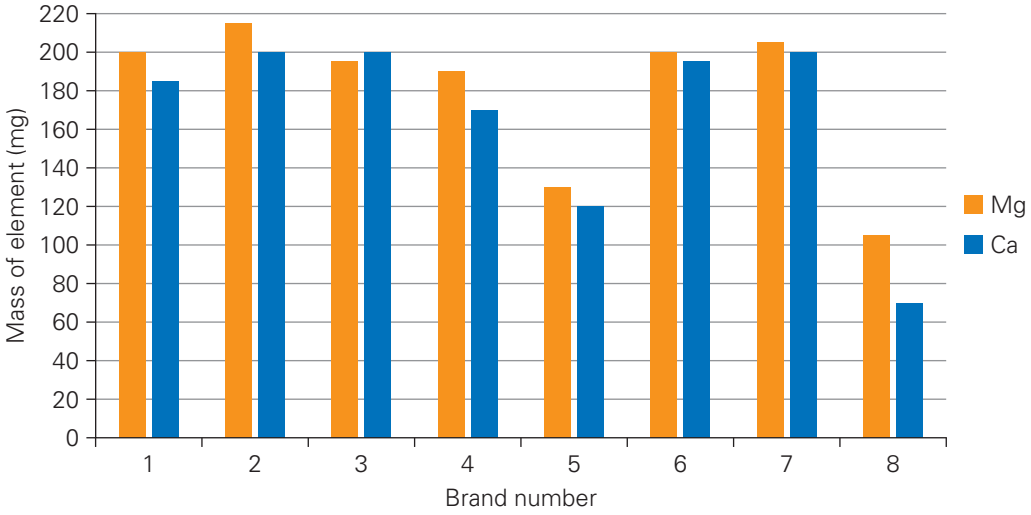

Figure 4.34 Mass of magnesium and calcium found in eight commercial supplement samples

1. **Identify** all samples that had less than the advertised 200 mg of magnesium.
2. Brand 3 advertised that the magnesium content was 200 mg ±10%. **Calculate** the minimum amount of magnesium that could be present in this advertised sample.
3. Use your answer to Question 2 to **clarify** whether brand 3 has a magnesium content within the advertised range.
4. Brand 5 is being investigated for false advertising with its claim that 'we have a more accurate calcium content than (brand 1)'. Explore this statement and **assess** its accuracy.
5. A spokesperson for brand 6 has stated that 'the calcium content is more difficult to maintain as it is a more reactive metal than magnesium'. **Contrast** the magnesium and calcium content in brand 6. Does this explanation match the data presented in Figure 4.34?
6. **Identify** the general trend between the mass of magnesium and the mass of calcium in a brand's supplements.
7. The 200 mg magnesium supplements are deemed to be falsely advertised if the content is found to be below 180 mg. **Compare** the data for the eight samples. Which brands have falsely advertised?
8. A magnesium content of over 220 mg would also be considered misleading advertising. Use the data to **justify** that no brand is providing misleading information in this regard.
9. Brand 7 has released a new series of magnesium and calcium supplements containing 250 mg of magnesium or calcium. Use your response to Question 5 to **decide** whether the samples of these products would contain more magnesium or calcium.

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STEM activity: Creating composite materials

Background information

Elements have very particular properties, but these properties alone are often not suitable for the range of engineering projects that are required in society. Elements therefore need to be chemically or physically combined to create materials with different properties that are more suited to particular tasks.

Materials engineers study the properties of materials such as metals, ceramics, nanomaterials (extremely small substances) and other substances. They may also combine different materials to produce new materials with properties combined from each of its parts. These are called 'composite materials'.

In composite materials, the combined initial materials do not bond or blend with one another, so it is easy to tell the different materials apart. Mud bricks are an example of a composite material. Mud bricks are made of straw and mud. Mud is strong if you press down on it but breaks when you bend it. Straw is strong if you pull on it, but it easily crumples. Mixing straw and mud together creates bricks that hold shape when squeezed or bent. Mud bricks are great as building blocks, whereas neither mud nor straw individually is good.

Figure 4.35 Concrete is a composite of cement and sand. The composite materials can be mixed **(a)** and then used to provide a strong foundation **(b)** for a building, particularly when combined with metal rods for stability.

DESIGN BRIEF

Create a composite material for the purpose of building a specific product.

Activity instructions

In small groups, consider the type of structure that you would like to build. For example, you could build a beam bridge, an aeroplane, a building or a chair. Then conduct some research and brainstorm what kind of properties you need in the material used to build the product. Think about what kinds of tests would be useful to determine if the material is suitable or not.

Next, design a prototype of the composite material and test it against these properties. Build and test the prototype. Then think of some ways it could be improved and test it again.

Suggested materials

- internet
- scissors
- ruler
- coins
- paper towels
- tape
- PVA glue
- popsicle sticks
- paper
- cardboard
- elastic bands
- string or yarn
- other materials, where possible

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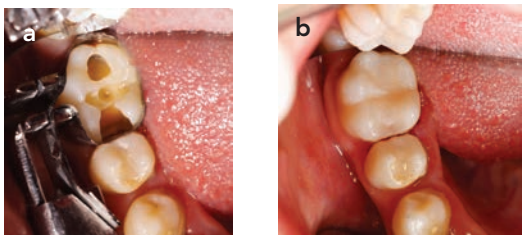

Figure 4.36 Modern dental fillings may use a composite material containing acrylic resin and glass. When these materials are combined, a strong and natural tooth-coloured filling is formed. **(a)** The liquid composite is added to the tooth **(b)** and then sets to a solid.

Research and feasibility

1. Research the two composite materials: glass fibre-reinforced concrete (GFRC) and steel-reinforced concrete.
   - **a)** Copy and complete the table below and add other properties you believe are important.
   - **b)** What are the differences and what are the benefits of one material over the other?
   - **c)** How did the discovery of each material change the way we use concrete?

	Glass fibre-reinforced concrete	Steel-reinforced concrete
Strength		
Benefits compared to concrete		
Temperature variance		

2. As a group, decide on a purpose for creating a new material for manufacture. Research the important properties and features the new composite material will require.

Design and sustainability

3. You will be testing composite materials made up of different ratios of component materials. List the ratios of each component material used in the composite that your group will be testing, and write the method for manufacturing and testing your composite material. (Think about the properties of your materials and which material would be the best.)
4. Design the best possible method to create your new composite material.
5. Discuss the sustainability of your material and its environmental impact. Your new material must have a positive environmental impact and be sustainable to manufacture.

Create

6. Manufacture the composite material in the various ratios set out in the design phase and allow it to set if required.
7. Test your material by applying forces to your material. Record the type of force (such as gravity).

Evaluate and modify

8. Evaluate the capabilities of the original materials compared to the new material. Discuss and explain the differences.
9. What are the maximum forces that could be applied to each ratio of component materials? Explain the effect of the ratios of the single materials when used as a composite material.
10. Suggest ways to improve the composite material. Should another material be added? Should the ratios of the component materials be altered?
11. Predict how the composite material might behave if it was constructed differently but with the same materials.

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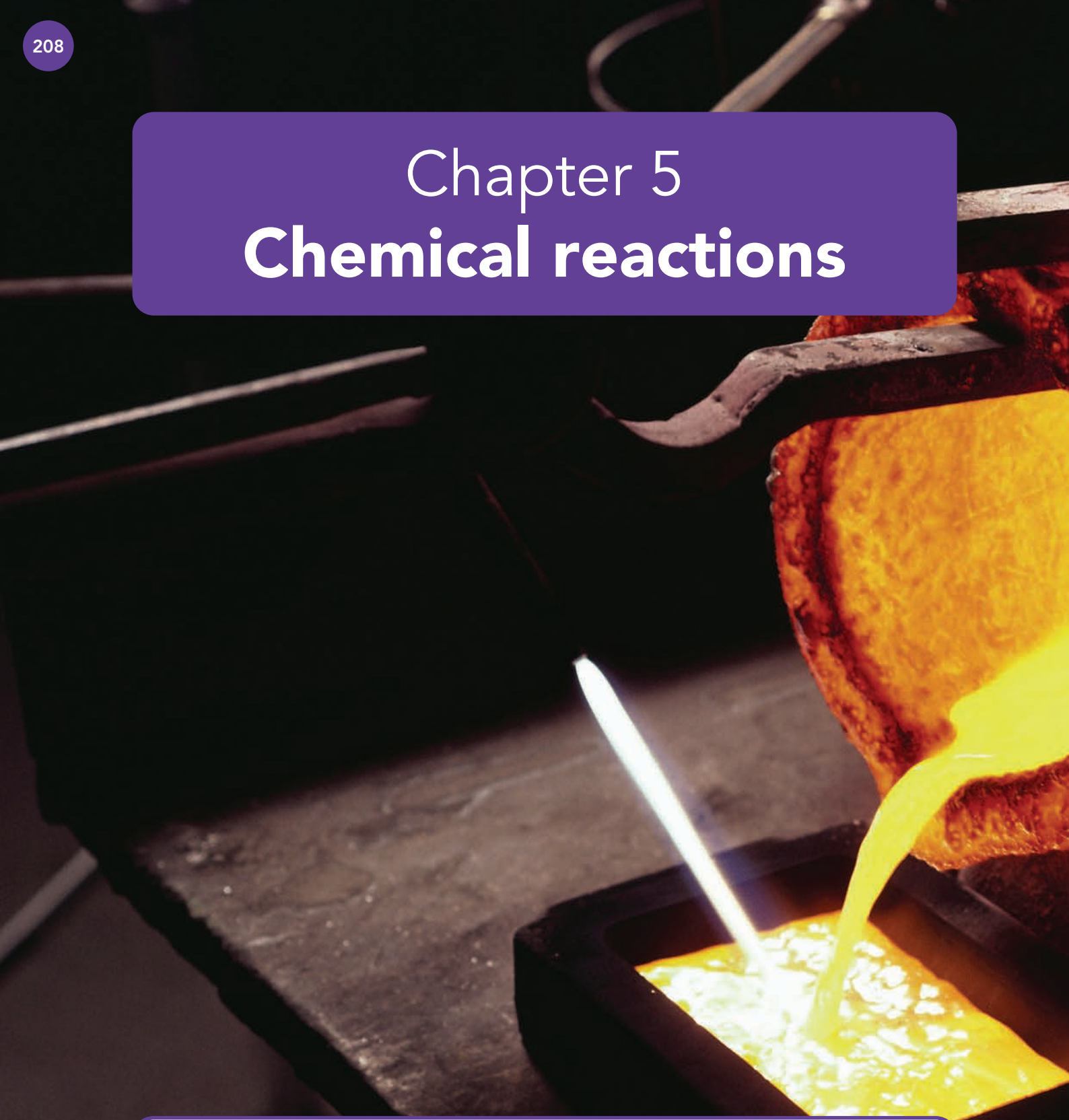
Chapter 5
Chemical reactions



Chapter introduction

The chemical industry produces a range of useful substances in vast quantities, many of which you could not do without. These products are a result of chemical reactions, which can be described in word equations, balanced symbol equations or particle diagrams. In this chapter, you will learn how to predict the products of common types of chemical reactions and to predict how changes in the conditions of a chemical reaction could affect the rate at which the reaction progresses. Finally, you will calculate the amount of reactants and products that are used and produced in a chemical reaction using the mole concept.

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Chapter map

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Curriculum content

Chemical sciences	
Reactions follow general patterns that help to predict the reaction products, including precipitation reactions and reactions of acids with bases, metals and carbonates; word and balanced chemical equations can be used to represent these reactions	
• modelling the balancing of chemical equations using molecular modelling kits, diagrams or simulations	5.1
• using indicators to identify acids and bases, and observing the changes in neutralisation reactions	5.3

• everyday applications of
  • precipitation reactions, such as water testing and precipitation of magnesium and calcium oxides in kettles and water pipes
  • acid reactions, such as indigestion, fire extinguishers and the treatment of acidic soil and bee stings
	5.2
	5.3

The rate at which a reaction occurs can be altered by changing factors, including temperature, concentration and the surface area of a reactant	

• investigating factors affecting the rate of reactions, such as changing the
  • temperature of the reactants
  • concentration of one or more reactants
  • surface area of a solid reactant
	5.4

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Extension

Year 11 ATAR Chemistry	
The mole is a precisely defined quantity of matter equal to Avogadro's number of particles	5.5
The mole concept relates mass, moles and molar mass and, with the law of conservation of mass; can be used to calculate the masses of reactants and products in a chemical reaction	5.5

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Glossary terms

acid
activation energy
agitating
aqueous
base
catalyst
chemical formula
coefficient
collisions
concentrated solution
concentration
diatomic
dilute solution
elementary entity
insoluble
metal displacement reaction
molar mass
mole
monatomic
neutralisation
particle diagram
pH
precipitation
pressure
products
reactants
reaction rate
reactivity series
relative atomic mass
salt
soluble
surface area
synthesis
thermal decomposition
word equation

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5.1 Representing chemical reactions

Learning goals

At the end of this section, I will be able to:

1. Represent chemical reactions using word and chemical equations.
2. Recall the correct use of state symbols in a chemical equation.
3. Balance a chemical equation.

WORKSHEET Representing chemical equations

VIDEO Indicators of chemical reactions

In a chemical reaction, chemical bonds in **reactants** are broken and new chemical bonds are formed to make the **products**. These chemical bonds can be ionic, metallic or covalent, as seen in Chapter 4. Reactants are the chemicals that are made to react together, and products are the chemicals that are produced in a chemical reaction. In this section, you will learn how to represent chemical reactions as word equations, balanced symbol equations and particle diagrams.

reactants the chemicals which react together in a reaction

products the chemicals produced in a reaction

word equation a chemical reaction written using the names of the reactants and products involved

chemical equation a chemical reaction written using the symbols and formulas of the reactants and products involved

Word equations

Word equations describe the reactants and products of a chemical reaction in words. Below is the word equation for the reaction of two common chemicals. Can you identify the reactants and the products?

sodium hydroxide + hydrochloric acid → sodium chloride + water ✓

Notice that all the reactants are on the left-hand side of the arrow and the products are on the right-hand side. It is very tempting, if you run out of paper, to write the same chemical reaction as in the example below.

sodium hydroxide + hydrochloric acid →
sodium chloride + water ✗

However, you should make sure that the reactants are always on the left and the products are always on the right of the arrow, as in the correct example above.

Quick check 5.1

1. **Correct** the following word equation: CO_2 + water → glucose + oxygen
2. **Identify** which of the following options should you **not** do if you are running out of paper and still have to finish writing a word equation.
   - A) Just carry on to the next line. It does not matter where you write the reactants and products.
   - B) Rewrite the equation, so it fits onto the piece of paper.
   - C) Split some of the reactants or products over two lines to ensure that all reactants are on the left of the arrow, and all products are on the right.

Symbol equations

A second way of representing a chemical reaction is by using a symbol equation or **chemical equation**. They are structured the same way as word equations but use chemical symbols and formulas instead of words to represent the substances in the reaction.

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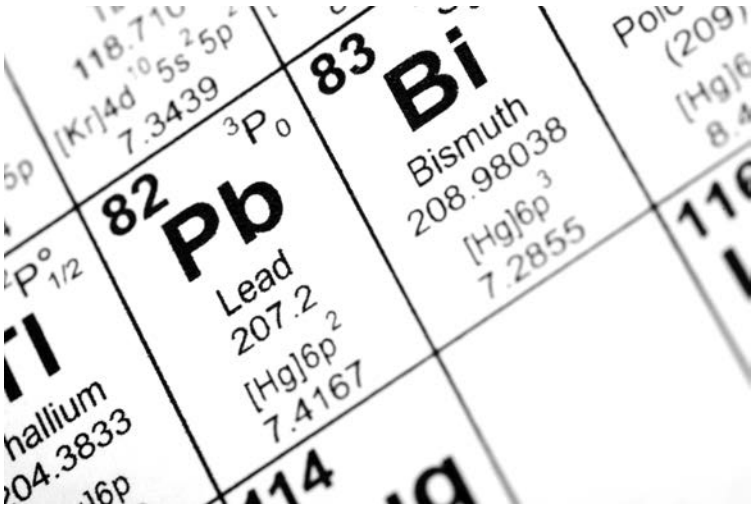

Figure 5.1 Lead is one of the elements with two letters in its chemical symbol (Pb). One is upper case (capital) the other is lower case. The symbol comes from its Latin name, *plumbum*.

Elemental symbols can be taken from the periodic table. Make sure they are written in the same way. That is, the first letter is capitalised and the second letter (if present) is lower case (see Figure 5.1).

All the noble gas elements on the periodic table exist as individual atoms on their own, as they generally don't participate in chemical bonding, and are described as being **monatomic**, meaning existing as one atom. However, many other non-metallic elements do not exist on their own. Instead, they tend to exist naturally as a gas or liquid with two atoms covalently bonded together. These elements are known as **diatomic**, meaning existing as two atoms. Table 5.1 lists the seven diatomic elements on the periodic table.

monatomic (also monoatomic) existing as one atom

diatomic a substance made up of two atoms bonded together

Element	Formula
Hydrogen	H_2
Nitrogen	N_2
Oxygen	O_2
Fluorine	F_2
Chlorine	Cl_2
Bromine	Br_2
Iodine	I_2

Table 5.1 Seven diatomic elements

Let's look at the word equation from before to see if we can turn it into a symbol equation.

sodium hydroxide + hydrochloric acid → sodium chloride + water

The word equation shows us that sodium hydroxide (NaOH) is reacting with hydrochloric acid (HCl) to form sodium chloride (NaCl) and water (H_2O). Using the symbols for these compounds, a chemical equation can be created, like the one below.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

This chemical equation shows you what happens when the compounds sodium hydroxide and hydrochloric acid react. The atoms are rearranged to form two new compounds: sodium chloride and water.

Quick check 5.2

1. **State** the number and type of atoms in one molecule of sucrose ($C_{12}H_{22}O_{11}$).
2. **Explain** the term 'diatomic molecule'.
3. **Write** a chemical equation with symbols for the reaction between iron (Fe) and chlorine (Cl_2) to make iron(II) chloride ($FeCl_2$).

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State symbols

Chemical equations give you more information than word equations with respect to the rearrangement of atoms within elements and compounds. You can add more information to chemical equations by using state symbols that show the physical states of the substances in a chemical equation. Table 5.2 summarises the symbols used for each of the four physical states.

State	Symbol	Example
Solid	(*s*)	iron
Liquid	(ℓ)	water
Gas	(*g*)	carbon dioxide
Aqueous	(*aq*)	salt water

Table 5.2 State symbols are used to represent the physical states of the substances in a chemical equation.

You may not be familiar with the term **aqueous** (*aq*). Aqueous is a term used to describe a solution of solute (solid, liquid or gas) dissolved in water, for example, salt water, NaCℓ(*aq*).

aqueous
a physical state of matter that means 'dissolved in water'

You can now make the chemical equation even more informative by adding in state symbols for the four substances in the equation.

$$NaOH(aq) + HC\ell(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$$

Figure 5.2 Ocean water is an aqueous solution because salt (sodium chloride) is dissolved in the water.

Most acids and alkalis you will come across in this chapter are aqueous. In this example, sodium hydroxide (NaOH) is aqueous as it has been made by dissolving solid sodium hydroxide in water. Likewise, hydrochloric acid is also aqueous as it is made by dissolving the acidic gas hydrogen chloride in water.

Quick check 5.3

1. **Describe** why salt water is considered an aqueous solution.
2. **Identify** which two of the following compounds would be given the state symbol (*s*) at room temperature: hydrogen gas, copper, sugar (sucrose), hydrochloric acid.

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Particle diagrams

particle diagram a representation of elements and compounds where atoms are drawn as balls or circles

Finally, you can also use **particle diagrams** to represent chemical reactions. In particle diagrams, pictures are used to show the atoms involved in a reaction. You can convert the chemical equation used previously to a particle diagram.

One of the advantages of using a particle diagram to represent a chemical reaction is that you can visualise how many atoms of each element are present. Another advantage is that you can see how the atoms have rearranged in the reaction. In the particle diagram shown in Figure 5.3, the bond between the sodium and oxygen in sodium hydroxide and the bond between hydrogen and chlorine in hydrochloric acid have been broken, and these atoms have bonded with other atoms to make different products. Note: In Chapter 4, we learned that ionic compounds, such as sodium hydroxide, bond in a three-dimensional lattice, but in a particle diagram you can show one unit for simplicity.

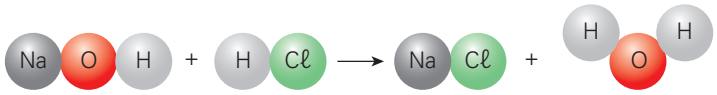

Figure 5.3 The particle diagram for the reaction between sodium hydroxide and hydrochloric acid

Quick check 5.4

1. **Define** a particle diagram.
2. **Explain** the main advantage of a particle diagram to represent chemical reactions.

Balancing chemical equations

WORKSHEET Balancing chemical equations

The law of conservation of mass states that mass is neither gained nor lost in a chemical reaction, but is always conserved. Therefore, the mass of reactants must equal the mass of the products in any chemical reaction. Atoms from the products cannot disappear, and similarly, atoms cannot just appear in the products.

WIDGET Balancing chemical equations

A balanced chemical equation has the same number and types of atoms on the left-hand side (reactants) as it does on the right-hand side (products). Looking at the diagram of the particles can make it easier to pinpoint when equations are not balanced.

For example, consider the following equation.

$$NaOH(aq) + HC\ell(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$$

To determine whether this equation is balanced or not, you need to count the number of each atom on both sides of the equation. It helps to do this in a table (as shown in Table 5.3), and it can also be easier to use the particle diagram, shown in Figure 5.4.

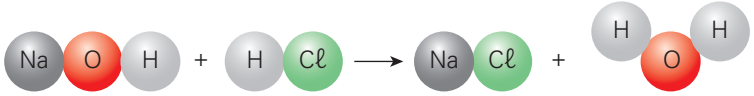

Figure 5.4 Particle diagram

	Number of atoms in the reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	1	1
Oxygen (O)	1	1
Hydrogen (H)	2	2
Chlorine (Cℓ)	1	1

Table 5.3 It helps to use a table to determine whether an equation is balanced or not. As there are the same number and types of atoms in both the reactants and products, you can determine that this is a balanced equation. Therefore, you do not need to modify it in any way.

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Figure 5.5 Equations with the same number and type of reactant atoms as product atoms are said to be balanced.

In another example, solid sodium metal (Na) reacts with chlorine gas ($C\ell_2$) to make solid sodium chloride (NaCℓ).

$$Na(s) + C\ell_2(g) \rightarrow NaC\ell(s)$$

Recording the number of each atom on both sides of the equation using the method you used in the previous example gives the results shown in Table 5.4.

	Number of atoms in the reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	1	1
Chlorine (Cℓ)	2	1

Table 5.4 Recording the number of atoms in this equation shows that the equation is unbalanced.

You should notice that there is one more chlorine atom in the reactants than there is in the products. This equation is not balanced.

When fixing an unbalanced chemical equation, it is not possible to change the formula of any of the substances in the equation, as you cannot change how the atoms have arranged themselves. For example, you cannot just simply remove one of the chlorine atoms in a $C\ell_2$ molecule. This is not how chlorine exists as it is covalently bonded and a diatomic molecule. The subscript numbers that appear after a chemical symbol indicate how many atoms of that element are present, and they cannot be altered.

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Instead, you should add more of each substance to both sides of the equation until the number of atoms balances out. Putting numbers in front of the chemical symbol or chemical formula changes the amount of that substance. For example:

Changing $O_2(g)$ to $\mathbf{2}O_2(g)$ means there are two molecules of oxygen gas instead of one.

The problem identified in the equation was that there were two atoms of chlorine in the reactants, but only one in the products. To even out the number of chlorine atoms, you can add another unit of NaCℓ to the products, as shown here.

$$Na(s) + C\ell_2(g) \rightarrow 2NaC\ell(s)$$

Use Table 5.5 to see if you have solved the problem.

	Number of atoms in the reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	1	2
Chlorine (Cℓ)	2	2

Table 5.5 Check the number of atoms after applying a change to see if the equation is now balanced.

You have solved the original problem of the unbalanced chlorine atoms, but by adding another unit of sodium chloride (NaCℓ), you have also altered the number of sodium atoms. Now these do not balance. To make them balance, you need to add another sodium atom to the reactants. See if this works using Table 5.6.

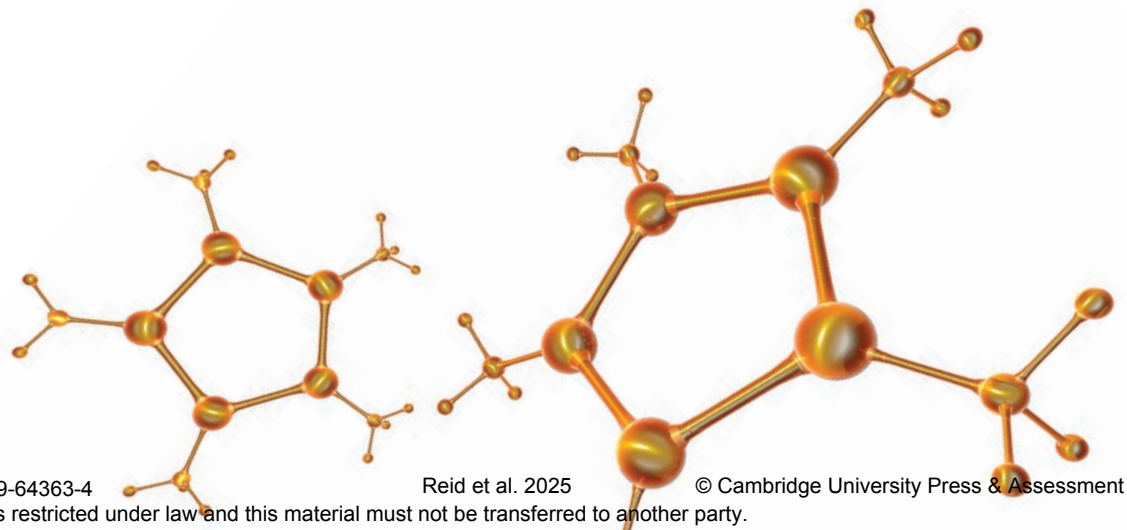
$$2Na(s) + C\ell_2(g) \rightarrow 2NaC\ell(s)$$

	Number of the atoms in the reactants (left-hand side)	Number of atoms in the products (right-hand side)
Sodium (Na)	2	2
Chlorine (Cℓ)	2	2

Table 5.6 The same number of atoms on the left- and right-hand side means the equation is now balanced.

coefficient
the number placed before a formula unit in a chemical equation to ensure it is balanced

By adding another unit of sodium chloride and a sodium atom, the equation is now balanced. All you have to remember is that the numbers before the chemical symbol (or **coefficients**) indicate the number of formula units, and the small subscript numbers indicate the number of atoms within the formula unit.



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Quick check 5.5

1. **Determine** whether the following chemical reactions are balanced or unbalanced.
   a) $Fe + O_2 \rightarrow Fe_2O_3$
   b) $H_2 + O_2 \rightarrow H_2O$
   c) $Zn + CuSO_4 \rightarrow Cu + ZnSO_4$
   d) $Be + C\ell_2 \rightarrow BeC\ell_2$
2. **Balance** these chemical equations. (Draw a particle diagram if you need help. To help you, the first two have spaces to show where you should add coefficients.)
   a) $\_\_ H_2 + O_2 \rightarrow \_\_ H_2O$
   b) $\_\_ Mg + O_2 \rightarrow \_\_ MgO$
   c) $Fe + O_2 \rightarrow Fe_2O_3$
   d) $Ca(OH)_2 + HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$
3. **Write** a balanced chemical equation for the reaction between aluminium ($A\ell$) and chlorine ($C\ell_2$) to make aluminium chloride ($A\ell C\ell_3$).

Explore! 5.1

VIDEO
The Haber process

The Haber process

The German scientist Fritz Haber and his assistant Robert Le Rossignol developed the Haber process, which was later industrialised by Carl Bosch. Haber was awarded a Nobel Prize for his efforts in 1918. The Haber process enabled the production of ammonia (NH_3) on a large scale by reacting nitrogen (N_2) gas with hydrogen (H_2) gas under optimum conditions.

Figure 5.6 A portrait of the scientist Fritz Haber

The largest ammonia plant in Australia is on the Burrup Peninsula in the Pilbara region of Western Australia. It produces around 330 000 tonnes each year. Ammonia is mainly used as a fertiliser.

1. Write a word equation for the production of ammonia in the Haber process.
2. Write a balanced symbol equation with state symbols.
3. The Haber process is a reversible reaction. Consider how this might be represented in word and symbol equations. Use the internet to help guide your research, if required.
4. Describe why the large-scale production of ammonia is so beneficial.

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Practical 5.1

Investigating the law of conservation of mass

Be careful
Wear appropriate personal protective equipment (safety glasses, disposable gloves and lab coat).

Aim
Investigate the conservation of mass in a chemical reaction

Theoretical equations
Reaction 1:

sodium hydroxide + iron(II) sulfate → iron(II) hydroxide + sodium sulfate

$$2NaOH(aq) + FeSO_4(aq) \rightarrow Fe(OH)_2(s) + Na_2SO_4(aq)$$

Reaction 2:

calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

Materials
- 4 mL of 1 mol L^{-1} iron(II) sulfate solution
- 5 mL of 1 mol L^{-1} hydrochloric acid solution
- 8 mL of 1 mol L^{-1} sodium hydroxide solution
- 1.5 to 2 cm piece of calcium carbonate
- 10 mL measuring cylinders × 2
- 125 mL conical flasks × 2
- plastic pipette
- electronic balance

Planning
Refer to the chemical reactions above. For each reaction, predict whether the mass will change during the reaction. Justify your reasoning for this based on details from the theoretical equation. Use the internet to identify the main hazards associated with using iron(II) sulfate, hydrochloric acid, sodium hydroxide and calcium carbonate. Write the hazards in your planning as part of your risk assessment, and how you might mitigate these risks.

Method
Part 1: Prepare the results table
Copy the results table into your science book.

Part 2: Measure the mass of the reactants and products for Reaction 1
1. Note the level of uncertainty for the balance, as stated on the instrument that you are using in the table.
2. Using a measuring cylinder, measure 8 mL of sodium hydroxide solution.
3. Using a second measuring cylinder, measure 4 mL of iron(II) sulfate solution.
4. Place the conical flask on the balance and press 'tare' to zero.
5. Pour the contents of both measuring cylinders into the conical flask.
6. Record the mass of the combined mixture.
7. Observe the chemical reaction taking place and record your observations.
8. When it is finished, record the mass of the final products in the flask.

continued …

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Part 3: Measure the mass of the reactants and products for Reaction 2

1. Using a measuring cylinder, measure 8 mL of hydrochloric acid solution.
2. Place the conical flask on the balance and press 'tare' to zero.
3. Pour the hydrochloric acid into the conical flask. Add the calcium carbonate to the plate beside the flask.
4. Record the mass of the two reactants.
5. Add the calcium carbonate into the conical flask.
6. Observe the chemical reaction taking place and record your observations.
7. When it is finished, record the mass of the final products in the flask.

Results

1. Calculate the change in mass for each reaction and record it in the results table.
2. Calculate the range of uncertainty and record it in the table.
3. Calculate the relative uncertainty and record it in the table.
   For example, uncertainty = ± 0.05 g

$$\text{relative uncertainty} = \frac{\text{uncertainty value}}{\text{average value}} \times 100 = \frac{0.05\text{ g}}{2.50\text{ g}} \times 100 = 2\%$$

Independent variable	Dependent variable					
	Initial mass (g)	Final mass (g)	Change in mass (g)	Uncertainty (± ____)	Relative uncertainty	Other observations
Reaction 1						
Reaction 2						

Discussion

1. Describe the change in mass for each of the reactions using data.
2. Discuss possible reasons for a change in mass in the two reactions.
3. Relate these results back to the law of conservation of mass and discuss any discrepancies.
4. Discuss whether the experimental data supports the predicted outcome shown in the chemical reactions on the previous page.
5. Uncertainty is a measure of the variability in data. Describe the relative uncertainty for each of the groups.
6. Identify possible limitations of this method.
7. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Try this 5.1

Modelling chemical equations

Consider the chemical equation for the combustion of methane:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Model this chemical reaction using the three methods below and count how many atoms of each element are on each side of the reaction. Is there a conservation of mass?

1. Draw a particle diagram.
2. Construct each molecule using a molecular modelling kit.
3. Simulate this reaction using the 'Balancing chemical equations' simulation on the PhET website.

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Summary of representing reactions

Table 5.7 summarises three ways in which a chemical reaction can be represented.

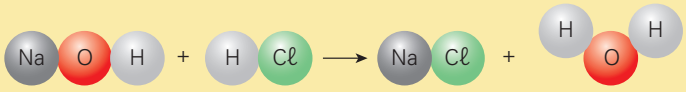
Type	Example
Word equation	sodium hydroxide + hydrochloric acid → sodium chloride + water
Balanced chemical equation with state symbols	$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$
Particle diagram	

Table 5.7 Three ways in which a chemical equation can be represented

Go online to access the interactive section review and more!

Section 5.1 review

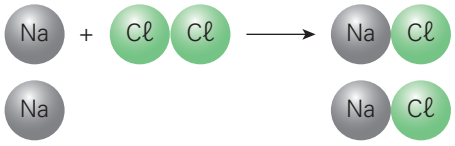
Online quiz

Section questions

Teachers can assign tasks and track results

Section 5.1 questions

Remembering

1. **Identify** the type of equation shown in the following examples.
   a) Carbon + oxygen → carbon dioxide
   b) $2Ca(s) + O_2(g) \rightarrow 2CaO(s)$
   c) 

2. **Name** the state symbols that would represent the following substances.
   a) Sodium chloride (salt)
   b) Sulfuric acid solution
   c) Water
   d) Nitrogen
3. **Identify** which of the following molecules are diatomic.
   a) H_2O
   b) CO_2
   c) N_2
   d) F_2
4. Sodium reacts with water to produce sodium hydroxide and hydrogen gas. The water will turn purple as sodium hydroxide (an alkali) is produced.
   a) **State** the reactants in the reaction.
   b) **State** the products in the reaction.
   c) **State** the word equation.
5. **Identify** the coefficients in the equations below.
   a) $2Ca + O_2 \rightarrow 2CaO$
   b) $2Fe + 3Cl_2 \rightarrow 2FeCl_2$
   c) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

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Understanding

6. **Describe** the composition of copper(II) sulfate ($CuSO_4$) in terms of the number of each type of atom in one unit.
7. **Explain**, using the term 'conservation of mass', why it is important that chemical equations are balanced.
8. **Demonstrate** the different ways of writing a chemical reaction by completing the following for the reaction between solid calcium (Ca) and liquid bromine (Br_2) to form solid calcium bromide ($CaBr_2$).
   a) Word equation
   b) Balanced chemical equation with state symbols
   c) Particle diagram

Applying

9. **Explain** why it is important to only change coefficients of formulas of substances in a chemical equation and not to change the subscripts.
10. **Balance** the following equation.

$$HNO_3 + Ca \rightarrow Ca(NO_3)_2 + H_2$$

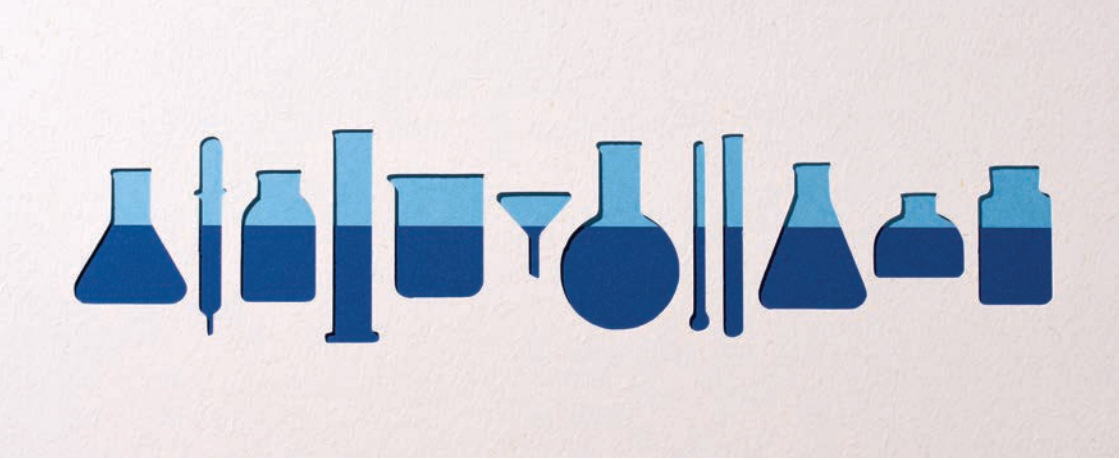
11. **Construct** a balanced symbol equation with state symbols for the reaction of potassium metal with oxygen to form solid potassium oxide (K_2O).
12. Electricity can be used to break down water (H_2O) into diatomic oxygen and diatomic hydrogen. There is no other reactant.
    a) **Construct** a balanced symbol equation with state symbols to show this.
    b) **Identify** how much more hydrogen is produced in this reaction compared to oxygen.

Analysis

13. **Analyse** whether the unbalanced equation below has been balanced correctly. If it hasn't, write the correct balanced equation.
    Unbalanced: $H_2O(g) + O_2(g) \rightarrow H_2O_2(\ell)$
    Balanced: $H_2(g) + O_2(g) \rightarrow H_2O_2(\ell)$

Evaluating

14. **Deduce** whether the following equations are balanced or unbalanced, and then correct the unbalanced equations.
    a) $Ca + Br_2 \rightarrow CaBr_2$
    b) $NaOH + HC\ell \rightarrow NaC\ell + H_2O$
    c) $CuO + C \rightarrow Cu + CO_2$
    d) $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$
    e) $Ag + H_2S + O_2 \rightarrow Ag_2S + H_2O$



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5.2 Types of chemical reactions

WORKSHEET
The reactivity series

Learning goals

At the end of this section, I will be able to:

1. Identify a reaction type and predict the products.
2. Identify the solubility of a salt.
3. Write balanced chemical equations for synthesis, decomposition, metal displacement and precipitation reactions.

This chapter will explore four common types of chemical reactions:

- synthesis
- decomposition
- metal displacement
- precipitation.

For these reactions, it is important that you can write balanced symbol equations and predict the products of the reaction.

Synthesis reactions

synthesis
a reaction in which two (or more) elements or reactants combine to form new substances or products

A **synthesis** reaction (sometimes called combination) involves two or more elements or reactants combining to form one new substance or product. Synthesis reactions can be represented in this way:

$$A + B \rightarrow AB$$

where A and B are the reactants and AB is the product.

An everyday example of a synthesis reaction is rust forming on iron. Iron metal reacts with oxygen gas in the air to form rust, as shown in the following equations.

Word equation:

$$\text{iron} + \text{oxygen} \rightarrow \text{iron(III) oxide}$$

Chemical equation:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

This reaction can be classified as a synthesis reaction as two reactants combine to form one new product. Another example is the synthesis of sodium chloride (table salt) using sodium metal and chlorine gas reactants.

Word equation:

$$\text{sodium} + \text{chlorine} \rightarrow \text{sodium chloride}$$

Chemical equation:

$$2Na(s) + C\ell_2(g) \rightarrow 2NaC\ell(s)$$

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Figure 5.7 Iron has rusted on this chainlink fence to form brown iron(III) oxide.

Explore! 5.2

Pyrolysis

Pyrolysis describes the burning of plant matter in a low-oxygen environment. You have likely seen this type of chemical reaction in action when watching a campfire and a dark smoke appears. While the surface of the wood has a lot of oxygen to burn, the inside of the wood is still burning but is in a low-oxygen environment. Some Aboriginal Peoples use the pyrolysis reaction for a variety of cultural purposes, including for medicine.

Figure 5.8 Some Aboriginal Peoples in Central Australia pyrolyse biomass in the form of twigs and leaves as a source of calcium oxide.

In Central Australia, Aboriginal Peoples of the area pyrolyse the plant matter of a plant species known to have a high calcium content. The calcium is converted to calcium oxide in the pyrolysis and is collected in the resulting ashes in a synthesis-type reaction. It can be described by the equation: $2Ca(s) + O_2(g) \rightarrow 2CaO(s)$. These ashes are then combined with the leaves of a medicinal plant for chewing. The calcium oxide enhances the release of the medicinal chemicals from the plant leaves, creating a very effective medicine.

This is only one example of how pyrolysis is used traditionally by Aboriginal Peoples. Explore some other ways that different groups of Aboriginal Peoples traditionally use the pyrolysis chemical reaction using appropriate sources for research.

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Did you know? 5.1

The hydrogen fuel cell

Hydrogen gas is considered a green or renewable fuel, and it can be combusted in oxygen gas to produce water and energy. The chemical equation for this reaction is:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(\ell) + \text{energy}$$

This is a synthesis reaction as two reactants combine to form one product. The reaction vessel is called a 'fuel cell'. The energy released from a fuel cell can be used to power vehicles using hydrogen fuel as a green alternative to petroleum combustion engines.

A collaboration between Fortescue Future Industries and ATCO has resulted in Perth's first green hydrogen refuelling station in Jandakot. Cars powered by a hydrogen fuel cell can refuel and drive with zero carbon emissions!

Figure 5.9 Hydrogen refuelling station in Western Australia

Decomposition reactions

Reactions where one reactant breaks up into multiple products is called a decomposition reaction. Decomposition reactions are essentially the opposite of synthesis reactions and can be represented in this way:

$$AB \rightarrow A + B$$

where AB is the reactant and A and B are the products.

For example, carbonic acid (H_2CO_3) is an ingredient in soft drinks. When you open a can of soft drink, the carbon dioxide that escapes is a result of a decomposition reaction that has occurred within the drink.

Word equation:

$$\text{carbonic acid} \rightarrow \text{water} + \text{carbon dioxide}$$

Chemical equation:

$$H_2CO_3(aq) \rightarrow H_2O(\ell) + CO_2(g)$$

thermal decomposition decomposition that occurs when a substance is heated

Some compounds break down when heated in a reaction called **thermal decomposition**.

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Did you know? 5.2

Thermal decomposition of iron ore

Australia is a world leader in the export of iron ore, which contains iron oxides such as iron(III) oxide (Fe_2O_3). However, this compound needs to be reacted to produce pure iron metal that can be used in alloys such as stainless steel.

Iron smelting is a process in which iron oxides are heated with carbon (in the form of coal) in a blast furnace to decompose the iron oxides into iron metal and carbon dioxide. The word and balanced symbol equations for this reaction are shown below.

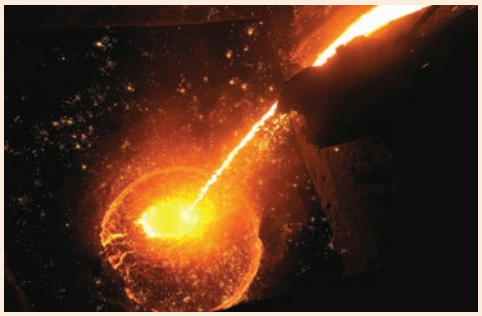

Figure 5.10 Molten iron spews out of a blast furnace where iron ores are reacted with carbon to form pure iron metal.

iron(III) oxide + carbon → iron + carbon dioxide

$$2Fe_2O_3(s) + 3C(s) \rightarrow 4Fe(\ell) + 3CO_2(g)$$

Smelting is not a clean process as coal has to be periodically shovelled into a blast furnace, and vast amounts of carbon dioxide are released into the atmosphere. Large amounts of energy are required to heat the furnace to over 1000°C.

Salt solubility

In some chemical reactions, an ionic compound called a **salt** is formed. A salt is not necessarily a word reserved for the table salt that you might put on your chips, sodium chloride. The term 'salt' is used to describe all ionic compounds that form in chemical reactions.

When salts are produced in an aqueous solution, some dissolve, and some do not. These salts can be described as **soluble** and **insoluble**, respectively. Soluble salts will have the state symbol (*aq*), and insoluble salts will have the state symbol (*s*).

The solubility of a salt can be predicted using a solubility table, such as that shown in Table 5.8.

salt
an ionic compound produced in a chemical reaction

soluble
a solute that dissolves in a solvent

insoluble
a solute that does not dissolve in a solvent

Soluble in water	Exceptions	
	Insoluble	Slightly soluble
Most chlorides	AgCℓ	$PbCℓ_2$
Most bromides	AgBr	$PbBr_2$
Most iodides	AgI, CuI, PbI_2	
All nitrates	No exceptions	
All ethanoates		
Most sulfates	$SrSO_4$, $BaSO_4$, $PbSO_4$	$CaSO_4$, Ag_2SO_4
Insoluble in water	**Exceptions**	
	Soluble	**Slightly soluble**
Most hydroxides	NaOH, KOH, $Ba(OH)_2$, NH_4OH	$Ca(OH)_2$, $Sr(OH)_2$
Most carbonates	Na_2CO_3, K_2CO_3, $(NH_4)_2CO_3$	
Most phosphates	Na_3PO_4, K_3PO_4, $(NH_4)_3PO_4$	
Most sulfides	Na_2S, K_2S, $(NH_4)_2S$	

Table 5.8 A solubility table

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For example, if sodium chloride (NaCℓ) was produced in a solution, we can identify that it will be soluble using the solubility table as most chlorides are soluble, and it isn't an exception. Therefore, in a chemical reaction it will have the state symbol (*aq*). In contrast, if copper(II) carbonate ($CuCO_3$) was produced in a solution, it will be insoluble as most carbonates are insoluble and it isn't an exception. Therefore, it will have the state symbol of (*s*) in a chemical reaction.

We will refer back to this table to determine the state symbol of any salt that is produced in solution.

Metal displacement reactions

reactivity series a series of metals ordered by their observable reactivity, from highest to lowest

metal displacement reaction when a more reactive metal removes a less reactive metal from its compound

Metals can be ranked in terms of their observable reactivity in a list called the **reactivity series**. The reactivity series describes the observable reactivity (most likely in terms of rate of reaction – see Section 5.4) of some common metals with acids and cations. Table 5.9 shows the order of reactivity of some common metals in the periodic table.

Metal
Potassium (K)
Sodium (Na)
Calcium (Ca)
Magnesium (Mg)
Aluminium (Aℓ)
Zinc (Zn)
Iron (Fe)
Nickel (Ni)
Tin (Sn)
Lead (Pb)
Copper (Cu)
Silver (Ag)
Gold (Au)

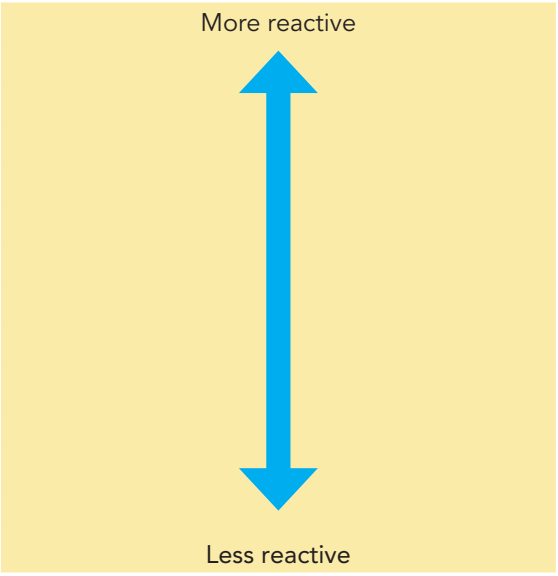

Table 5.9 A reactivity series of common metals

The reactivity series shows that tin is more reactive than lead and that zinc is more reactive than gold, for example. Potassium is the most reactive metal listed, while gold is the least reactive metal listed.

Quick check 5.6

1. **Decide** whether the following statements are true or false. If false, **give** a reason why.
   a) Potassium is the most reactive metal in the reactivity series shown in Table 5.9.
   b) Silver is less reactive than gold.
   c) Group 1 metals are the most reactive in the reactivity series.
2. **Name** the only group 13 element in the reactivity series shown in Table 5.9.

Using the reactivity series, you can predict the outcome of a particular type of reaction involving these metals, called a **metal displacement reaction**. In a displacement reaction, an ion of a more reactive metal will displace (remove or replace) an ion of a less reactive metal from a solution of its compound. The following is an example:

copper(II) sulfate + iron → iron(II) sulfate + copper

$$CuSO_4(aq) + Fe(s) \rightarrow FeSO_4(aq) + Cu(s)$$

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In this reaction, because iron is more reactive than copper, the iron atom loses two electrons to form an Fe^{2+} ion, and it displaces (or removes) the copper ion (Cu^{2+}) from its compound. The iron ion (Fe^{2+}) joins with the sulfate ion (SO_4^{2-}), and the Cu^{2+} ion gains two electrons to form copper metal. The iron(II) sulfate salt product is soluble on the solubility table, and has a state symbol of (*aq*). So what happens when the metal on its own is less reactive than the metal in the compound?

zinc sulfate + tin → X

$ZnSO_4(aq) + Sn(s) \rightarrow X$

In this case there is no reaction. Tin is not reactive enough because it is lower in the reactivity series than zinc, so it cannot remove the zinc from its compound.

Practical 5.2

Metal displacement reactions

Be careful

To avoid risk of contamination from chemicals:

- wear safety glasses and appropriate personal protective equipment at all times
- wash your hands after the practical.

Aim

To determine the order of reactivity of metals by the outcome of displacement reactions

Prior understanding

The periodic table was originally developed by grouping together elements that share common physical and chemical properties. The periodic table reveals trends and patterns of chemical properties (such as reactivity) that are determined by the underlying structure of each element.

VIDEO Metal displacement reactions

You will investigate the reactivity of metals using displacement reactions. This is a type of reaction involving a metal salt solution (a metal salt is a compound made from a combination of a metal and a non-metal) and a pure metal. Pure metals with a higher reactivity than the metal within the salt solution will react and 'push out' (displace) the metal that is within the salt solution, forcing the less reactive metal into its pure element form.

Materials

- pieces of each metal (zinc, magnesium, copper) × 3
- 1 dropper bottle of 1 mol L^{-1} zinc sulfate
- 1 dropper bottle of 1 mol L^{-1} magnesium sulfate
- 1 dropper bottle of 1 mol L^{-1} copper(II) sulfate
- dimple tile
- tweezers

Planning

1. Develop a hypothesis using the reactivity series as to how the position of a metal in the reactivity series will affect its reactivity with a metal lower in the series.
2. Draw a results table that will allow you to collect sufficient data.

Method

1. Add three drops of copper(II) sulfate to four dimples in a row, as shown in Figure 5.11.
2. Add three drops of magnesium sulfate to four dimples in a row.
3. Add three drops of zinc sulfate to four dimples in a row.

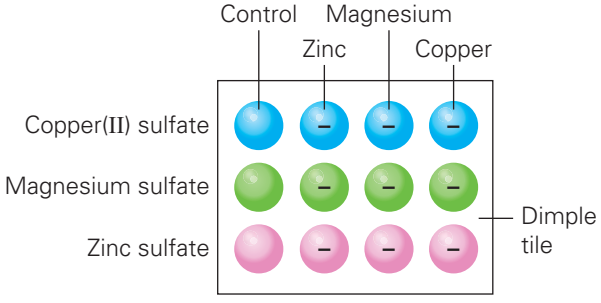

Figure 5.11 Arrangement of solutions on dimple tile

4. Add a piece of the first test metal to each dimple in the second column.
5. Repeat step 4 for each of the other two test metals, placing them in the third and fourth columns of dimples. Wait 10 minutes before recording your observations in the results table.

continued …

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Discussion

1. Describe the observations you used to determine whether a displacement reaction had taken place.
2. Identify the reactions that did not show displacement. What can you conclude from this result?
3. Write word equations for each of the successful displacement reactions.

Conclusion

1. Make a claim about the order of reactivity of the elements in this experiment.
2. Support your statement by referring to your experimental data.
3. State whether your hypothesis was supported or not.

Quick check 5.7

1. For the following mixtures of metals and metal compounds, **state** whether a reaction will occur.
   a) Iron(II) chloride + nickel
   b) Copper(II) sulfate + zinc
   c) Iron(II) sulfate + aluminium
   d) Sodium sulfate + gold
2. **Write** a balanced chemical equation for a metal displacement reaction that occurs spontaneously.

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Explore! 5.3

Applications of precipitation reactions

Precipitation reactions have many real-world impacts and applications. Use the internet to search for the chemical equation responsible for the following:

1. the formation of painful kidney stones
2. the formation of scale on a kettle
3. the removal of metal ions from drinking water.

Figure 5.12 A kidney stone is a precipitation reaction that occurs in the human body. Kidney stones can be painful to excrete.

Precipitation reactions

Chemical reactions that involve the mixing of two salt solutions to produce an insoluble solid are called **precipitation** reactions. This is because the solid that is formed is a called a precipitate. Precipitates have a variety of colours, and some are used as pigments in paint.

precipitation a reaction that involves the mixing of two solutions to produce a solid called a precipitate

For example, when a blue solution of copper(II) nitrate and a colourless solution of potassium hydroxide are added together, a blue precipitate, copper(II) hydroxide, forms. This precipitate is also predicted as insoluble on the solubility table. This observation is depicted in Figure 5.13.

Word equation:

copper(II) nitrate + potassium hydroxide → copper(II) hydroxide + potassium nitrate

Chemical equation:

$$Cu(NO_3)_2(aq) + 2KOH(aq) \rightarrow Cu(OH)_2(s) + 2KNO_3(aq)$$

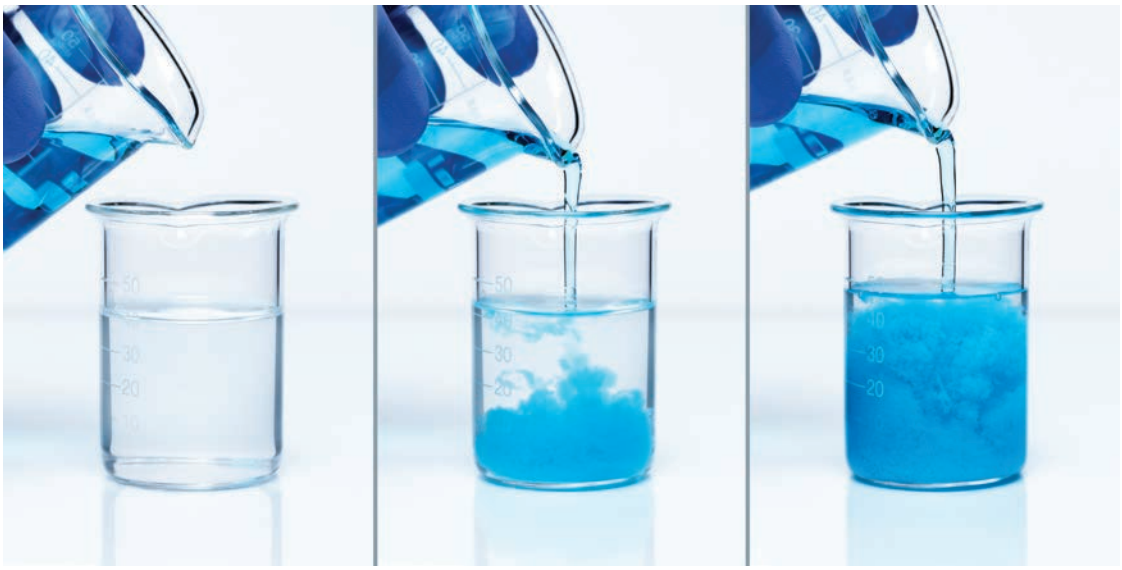

Figure 5.13 A blue solution is added to a colourless solution to form a blue precipitate in a colourless solution.

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Did you know? 5.3

Fermentation of cycad seeds

When James Cook's fleet arrived in Australia in 1770, many of his crew became very ill after consuming the toxic seeds of a cycad plant. Many Aboriginal Peoples, including those in contact with the Zamia palm (*Macrozamia riedlei*) in south-west Australia, had already mastered the detoxification processes of the seeds. Processes include grinding and washing the seeds with water to remove soluble toxic chemicals and fermenting the seeds by allowing mould to grow on them, which breaks down the toxic chemicals. These techniques allow Aboriginal Peoples of the area to prepare meals from the seeds without harm from toxic chemicals.

Figure 5.14 Seeds of a zamia palm (*Macrozamia riedlei*) in south-west Australia

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Section 5.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 5.2 questions

Remembering

1. **Name** four types of chemical reactions.
2. **Recall** the general equation for a decomposition reaction.

Understanding

3. **Write** a balanced equation for the decomposition of calcium carbonate ($CaCO_3$) to calcium oxide (CaO) and carbon dioxide (CO_2).
4. **Write** a balanced equation for the reaction of lead(II) nitrate ($Pb(NO_3)_2$) and sodium iodide (NaI) to form the yellow solid lead(II) iodide (PbI_2) and sodium nitrate ($NaNO_3$).

Applying

5. **Predict** the precipitate of the reaction between nickel(II) chloride and sodium hydroxide (NaOH).

Analysing

6. **Analyse** the following chemical equation occuring in aqueous solution and add state symbols:

$$Zn(CH_3COO)_2 + (NH_4)_3PO_4 \rightarrow NH_4CH_3COO + Zn_3(PO_4)_2$$

7. **Explain** the importance of the synthesis reaction that takes place in a hydrogen fuel cell.

Evaluating

8. **Write** a balanced chemical equation, with state symbols, for the metal displacement reaction of solid lead (Pb) with a solution of silver nitrate ($AgNO_3$).
9. **Write** a balanced chemical equation for the reaction of a solution of barium hydroxide with a solution of potassium sulfate.

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5.3 Acid reactions

Learning goals

At the end of this section, I will be able to:

1. Explain the meaning of pH and the pH scale.
2. Write balanced chemical equations for the three types of neutralisation reactions.

WORKSHEET Making plastics

In this section, you will learn about three types of reactions involving **acids**: acid–metal, acid–**base** and acid–carbonate reactions.

acid a substance that, when dissolved in water, causes the pH of the solution to fall below 7

base a substance that, when dissolved in water, causes the pH of the solution to rise above 7

pH a scale of the degree of H^+ ion concentration in an aqueous solution

concentration the amount of solute dissolved in a solvent

pH

Acids and bases can be defined by their concentration of hydrogen ions, H^+, in solution and quantified using the **pH** scale. pH stands for 'potential of hydrogen' and is a scale of the **concentration** of H^+ in a solution.

Acids produce H^+ in solution, and the more hydrogen ions, the lower the pH. Bases (also called alkalines) produce hydroxide ions, OH^-, in solution, which react with acids, lowering the H^+ concentration. The lower the concentration of H^+, the higher the pH. Neutral water – that is, neither acidic nor basic at 25°C – has a neutral pH of 7.

The pH scale generally ranges from 0–14 and can be observed using a universal indicator, which changes colour depending on the concentration of H^+ ions present in solution. Red, orange and yellow colours indicate acids; green indicates neutral; and blue and purple indicate bases.

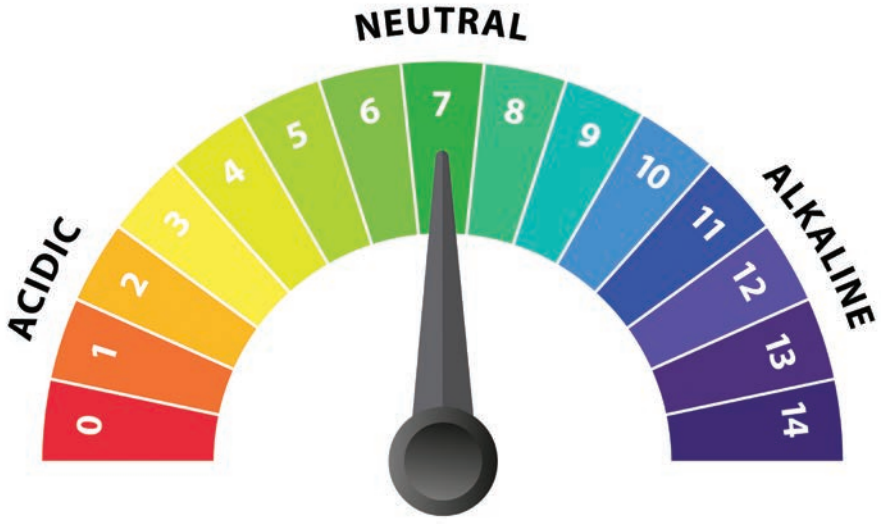

Figure 5.15 The pH scale with colours of universal indicator

Acids are sour and can sting or burn the skin. You can find some common acids in your kitchen, for example, lemon juice and vinegar. Bases generally have a soapy feel and include hand soaps and oven cleaner.

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Salts formed from acid reactions

Before we learn about acid reactions, it is important to know how to predict the common salt products of these reactions. The type of acid used affects the name and formula of the salt produced. Table 5.10 summarises the type of salt formed when different acids react. Note that these acids will always be in aqueous solution when using state symbols.

Type of acid	Formula	Type of salt
Hydrochloric acid	$HC\ell$	Chloride
Nitric acid	HNO_3	Nitrate
Sulfuric acid	H_2SO_4	Sulfate
Phosphoric acid	H_3PO_4	Phosphate
Ethanoic acid	CH_3COOH	Ethanoate

Table 5.10 A summary of the type of salt formed when different acids react

The other reactant in acid reactions will be, or contain, a metal. For example, the base called sodium hydroxide contains the metal sodium, and the carbonate called calcium carbonate contains the metal calcium.

The reactant other than the acid provides us with the first name of the salt. The type of acid provides the second name of the salt. Table 5.10 summarises how to predict the name of a salt produced in reactions that involve acids. You can then use the rules for writing ionic formulas from Chapter 4 to write the chemical formula of the salt.

Reactant 1	Metal present	Reactant 2: type of acid	Type of salt	Name of salt	Formula of salt
Magnesium (metal)	Magnesium	Hydrochloric acid	Chloride	Magnesium chloride	$MgC\ell_2$
Calcium hydroxide (base)	Calcium	Nitric acid	Nitrate	Calcium nitrate	$Ca(NO_3)_2$
Sodium carbonate (carbonate)	Sodium	Sulfuric acid	Sulfate	Sodium sulfate	Na_2SO_4

Table 5.11 Examples of how to name the salt produced in the three types of acid reactions

Quick check 5.8

1. **Describe** the pH range of acids.
2. **Name** a household acid and an acid used in your science laboratory.
3. **Name** the salt produced when calcium carbonate reacts with sulfuric acid.
4. **Describe** the two rules for naming a salt.

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Acid–metal reactions

Acid–metal reactions occur when an acid reacts with a metal to produce a salt and hydrogen (H_2). The hydrogen produced in the reaction can be identified using a simple squeaky pop test. In that test, when a flame is placed near the gas produced, a 'squeaky pop' will be heard as evidence that the gas produced is hydrogen.

The general word equation for any acid reacting with any metal is:

$$\text{acid} + \text{metal} \rightarrow \text{salt} + \text{hydrogen}$$

When a solution of hydrochloric acid reacts with solid magnesium, the salt magnesium chloride is formed, and the other product in the reaction is hydrogen:

$$\text{hydrochloric acid} + \text{magnesium} \rightarrow \text{magnesium chloride} + \text{hydrogen}$$

$$2HC\ell(aq) + Mg(s) \rightarrow MgC\ell_2(aq) + H_2(g)$$

Remember that the first part of the salt name comes from the metal and the second part comes from the type of acid used. Hydrogen is produced no matter what the acid or metal is. The reactivity of acid–metal reactions can also be predicted by looking at the reactivity table (see Table 5.9). In fact, the least reactive metals (gold, silver, copper) do not react with dilute acids, and there is no visible reaction.

The reaction between acids and metals is a problem in everyday life. Acid rain that forms from volcanic activity or industrial chemistry pollution can cause damage to buildings made of metals.

Figure 5.16 The orange toxic water produced here is due to the reaction of acid rain with the metal in this abandoned mine.

Quick check 5.9

1. **State** the general word equation for when a metal reacts with any acid.
2. **List** three metals that do not react with dilute acids.
3. **Complete** the word equation and then balanced chemical equation below.

nitric acid + _____ → zinc _____ + hydrogen

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Practical 5.3

Reaction of acids with metals

Be careful
Wear appropriate personal protective equipment.

VIDEO
Reaction of acids with metals

Aim

To observe what happens when metals react with acids

Materials

- 2 mol L^{-1} dilute hydrochloric acid
- 0.5 mol L^{-1} dilute sulfuric acid
- small granules of zinc and iron
- 5 cm strip of magnesium ribbon
- test tubes × 12
- test-tube rack
- wooden splints or matches
- Bunsen burner (if using wooden splints)

Method

1. Copy the results tables into your science book.
2. Place the 12 test tubes in the test-tube rack.
3. In three of the test tubes, add 10 mL of hydrochloric acid.
4. In another three test tubes, add 10 mL of sulfuric acid.
5. To each of the hydrochloric acid test tubes, add a different type of metal. Invert another test tube and place it over the top of the test tube and note your observations. Note: Ensure all metal samples have been cleaned before adding them to the acid. Also note that the reaction between the acid and metals may be rather slow and not produce enough hydrogen gas to cause a pop.
6. After about 30 seconds, light a wooden splint, lift the inverted test tube (keeping it inverted) and hold the flame beneath the mouth of the inverted test tube. Again, record your observations.
7. Add the same types of metal to the test tubes containing sulfuric acid, then place inverted test tubes over the top of the test tubes and note your observations.
8. After about 30 seconds, light a wooden splint, lift the inverted test tube (keeping it inverted) and hold the flame beneath the mouth of the inverted test tube. Again, record your observations.

Results

Table showing reactions with hydrochloric acid

Metal	Observations	Hydrogen produced?

Table showing reactions with sulfuric acid

Metal	Observations	Hydrogen produced?

Discussion

1. Discuss which of the metals reacted with the hydrochloric and sulfuric acids. How did you know?
2. Write word equations for each of the reactions you carried out in this practical.
3. State what happened to some of the reactions when the lit splint was put at the mouth of the inverted test tube.
4. Explain what this experiment tells you about the reactivity of metals.
5. During this reaction, you may have felt the temperature of the reaction increase. Recall the name of this type of reaction.

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Acid–base (neutralisation) reactions

Acid–base reactions occur when any acid reacts with any base to produce a salt and water. Notice that a salt is produced, just like in acid–metal reactions, but instead of hydrogen being the other product, water is made. A base is a substance that typically contains an oxide (O^{2-}) or hydroxide (OH^-) anion. Bases that you will come across in your science laboratory include sodium hydroxide, calcium hydroxide and magnesium hydroxide.

Figure 5.17 Copper ions can be leached from rock containing copper(II) oxide using an acid–base reaction.

The general word equation for any acid reacting with any base is:

acid + base → salt + water

For example, when a solution of nitric acid reacts with a solution of sodium hydroxide, the salt sodium nitrate is formed:

nitric acid + sodium hydroxide → sodium nitrate + water

$HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(\ell)$

The same reaction occurs with metal oxides. For example, if a solution of sulfuric acid was made to react with solid copper(II) oxide, a copper(II) sulfate salt would form.

Sulfuric acid + copper(II) oxide → copper(II) sulfate + water

$H_2SO_4(aq) + CuO(s) \rightarrow CuSO_4(aq) + H_2O(\ell)$

A special type of acid–base reaction is the reaction of an acid with the base ammonia (NH_3). This type of reaction only forms an ammonium salt, and not water. For example, when a solution of hydrochloric acid reacts with a solution of ammonia, ammonium chloride salt is formed:

hydrochloric acid + ammonia → ammonium chloride

$HC\ell(aq) + NH_3(aq) \rightarrow NH_4C\ell(aq)$

neutralisation
a reaction between an acid and a base, generally forming a solution that has a pH of 7

Acid–base reactions are also known as **neutralisation** reactions. This is because when acids and bases with the same volume and concentration react, they generally make a solution with a neutral pH (pH 7). Examples include soothing an alkaline wasp sting with ethanoic acid in vinegar; adding calcium oxide (lime) to neutralise acidic soils; and leaching Cu^{2+} ions from copper(II) oxide ores with sulfuric acid.

Figure 5.18 A wasp sting injects a base into human skin.

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Practical 5.4

Neutralisation reactions

Be careful
Wear appropriate personal protective equipment.

Aim

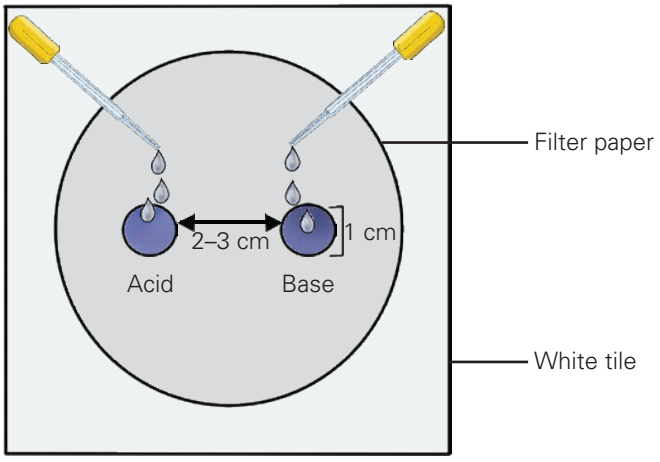
To observe what happens when acids react with bases

Materials

- 0.1 mol L^{-1} sodium hydroxide
- 0.1 mol L^{-1} hydrochloric acid
- sheet of filter paper
- white tile
- pencil
- universal indicator solution
- pH colour chart (full range)
- pipette × 2

Method

1. Using a pencil, draw two circles on the filter paper as shown in the diagram.
2. Label one of the circles 'acid' and the other one 'base'.
3. Use a pipette to place three drops of hydrochloric acid into the 'acid' circle.
4. Using another pipette, place three drops of sodium hydroxide into the 'base' circle.
5. Wait until the solutions soak into the filter paper. If the solutions don't meet in the middle, add more drops to both circles (ensure you add an equal number of drops to both circles).
6. Now add a three drops of universal indicator solution to the area where the acid and base have met.



Results

1. Compare the colour on the filter paper to a pH colour chart. Was the reaction neutralised?
2. Record your observations in your science book.

Discussion

1. Describe what you observed when adding the universal indicator.
2. Explain your observations.
3. Identify the type of reaction you carried out in this experiment.
4. Write a word equation for the reaction you investigated.
5. To demonstrate this type of reaction, explain why it is important to use the same concentration and volume of acid and base.

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Science inquiry 5.1

Dry fire extinguishers

Not all fire extinguishers are equipped with carbon dioxide gas to suffocate a fire. In Australia, dry fire extinguishers are the most common type and are often called ABE fire extinguishers. The dry chemical used is a fine powder of ammonium dihydrogenphosphate salt, which when applied to a fire, produces a barrier for oxygen and suffocates the fuel's ability to burn.

This powdered salt is produced from an acid + base reaction, namely phosphoric acid + ammonia:

$$H_3PO_4(\ell) + NH_3(g) \rightarrow NH_4H_2PO_4(s)$$

Figure 5.19 ABE fire extinguishers will have a sign like this to identify them.

The next time you see an ABE extinguisher, remember that it contains a salt of an acid + base reaction!

Quick check 5.10

1. **State** the general word equation for when a base reacts with an acid.
2. **Identify** the name for a reaction between an acid and a base.
3. **Complete** the word and then chemical equation below.

sulfuric acid + _____ → iron _____ + water

Acid–carbonate reactions

Acid–carbonate reactions occur when any acid reacts with any metal carbonate (CO_3^{2-}, e.g. $CaCO_3$) or metal hydrogencarbonate (HCO_3^-, e.g. $Ca(HCO_3)_2$) to produce a salt, water and carbon dioxide. As with acid–metal and acid–base reactions, a salt is produced, but the other products are different. You can test for the presence of carbon dioxide produced in an acid–carbonate reaction by bubbling the gas through limewater. Limewater ($Ca(OH)_2$) goes from colourless to milky white in the presence of carbon dioxide due to the precipitation of calcium carbonate:

$$Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(\ell)$$

The general word equation for any acid reacting with any carbonate or hydrogencarbonate is:

acid + metal (hydrogen)carbonate → salt + water + carbon dioxide

When a solution of sulfuric acid reacts with solid calcium carbonate or calcium hydrogencarbonate, the salt calcium sulfate is formed:

sulfuric acid + calcium (hydrogen)carbonate → calcium sulfate + water + carbon dioxide

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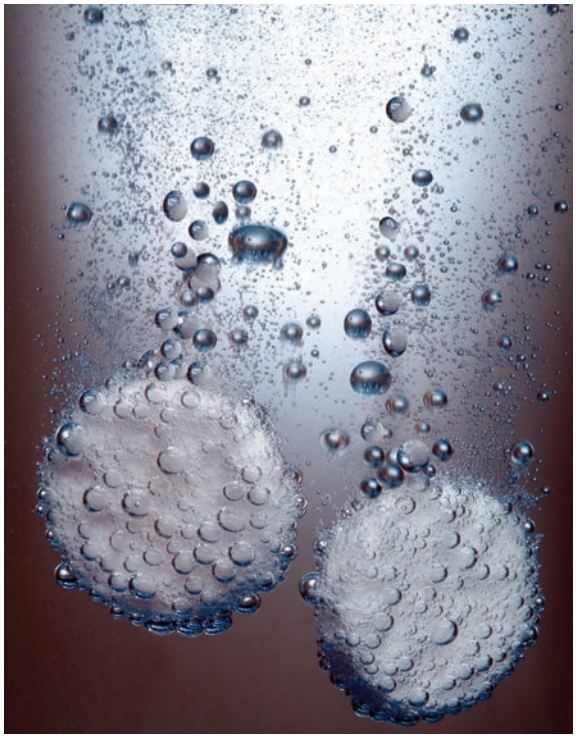

Figure 5.20 Antacid tablets react with stomach acids to produce a salt, carbon dioxide and water.

As a balanced chemical equation, the reactions with calcium carbonate (Eq. 1) or calcium hydrogen carbonate (Eq. 2) can be described as follows:

$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$ Equation 1

$H_2SO_4 + Ca(HCO_3)_2 \rightarrow CaSO_4 + 2H_2O + 2CO_2$ Equation 2

Acid–carbonate reactions are common in antacid tablets used to ease symptoms of acid reflux. The excess acid in the stomach is neutralised by the ingestion of sodium carbonate and sodium hydrogencarbonate in the antacid tablet. Just be prepared to burp the carbon dioxide gas produced!

Explore! 5.5

Weathering

Headstones are an important insight into what life used to be like and often hold huge sentimental value. The two pictures on the right show headstones of a similar age. The headstone in Figure 5.21 is made of limestone (calcium carbonate), and the one in Figure 5.22 is made of granite.

Figure 5.21 Limestone headstone

Figure 5.22 Granite headstone

1. Describe the observations you can make about the condition of the headstones in each picture.
2. Explain why it is more difficult to read the inscriptions on the limestone (calcium carbonate) headstone than on the granite headstone.
3. Write a word equation to explain your ideas in Question 2.
4. Despite the obvious difference in durability between granite and limestone, most of the headstones found in graveyards are made of limestone. Why do you think this is?
5. How could you reduce the degradation of limestone headstones?

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Quick check 5.11

1. **State** the general word equation for when any metal carbonate reacts with any acid.
2. **Describe** the test that shows the presence of carbon dioxide.
3. **Complete** a correct word equation below for a carbonate or hydrogencarbonate.
   hydrochloric acid + _____ → potassium _____ + water + carbon dioxide

Practical 5.5

Reactions of acids with metal carbonates

Be careful
Ensure appropriate personal protective equipment is worn.

Aim

To observe what happens when acids react with metal carbonates

Materials

- 1 mol L^{-1} nitric acid
- calcium carbonate powder
- limewater
- test tubes × 2
- delivery tube
- test-tube rack
- spatula
- rubber stopper with hole

Method

1. Add about 10 mL of nitric acid into one of the test tubes.
2. Add about 10 mL of limewater into the other test tube and place both test tubes into the test-tube rack.
3. Add a heaped spatula of calcium carbonate into the test tube containing the nitric acid, and at the same time place the rubber stopper on top of this test tube and the delivery tube into the limewater (see Figure 5.23).

Results

Record your observations.

Discussion

1. Write a word equation for the reaction you investigated.
2. Describe how your observations prove that carbon dioxide was present.
3. Research the reaction between carbon dioxide and limewater to explain your observations.

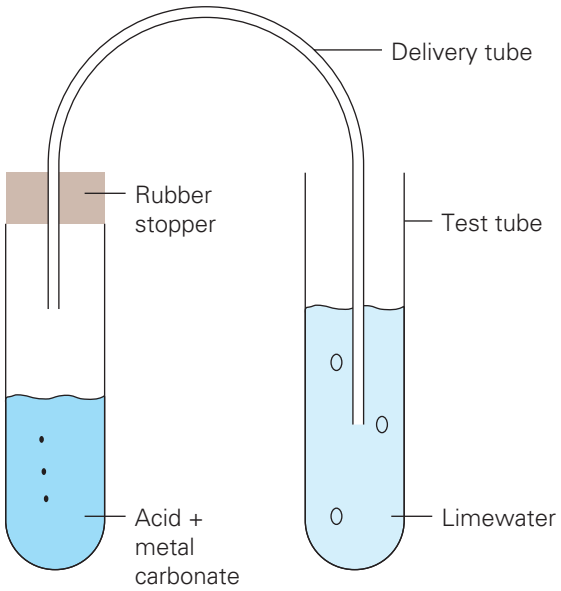

Figure 5.23 Testing for the presence of carbon dioxide using a delivery tube

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The Contact process

Sulfuric acid is one of the most important compounds made in the chemical industry. It is used to make hundreds of other useful compounds, such as fertilisers, paints and paper.

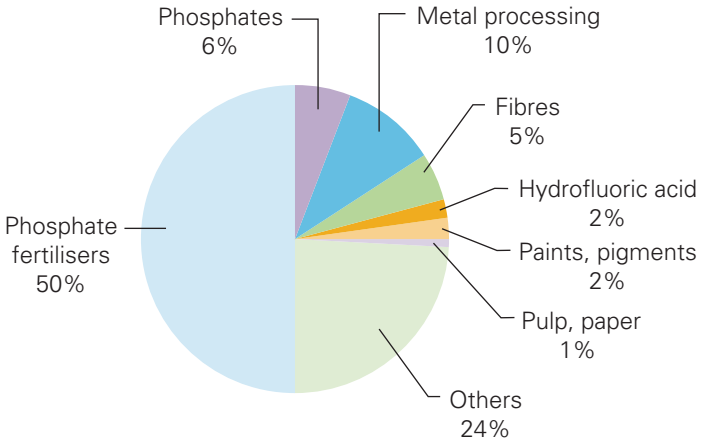

Figure 5.24 Sulfuric acid is required for the production of many substances.

catalyst
a substance that speeds up a chemical reaction by lowering the energy needed to break and form bonds (activation energy), and does not get used up in the process

Sulfuric acid is made in the Contact process, in which sulfur is combusted in oxygen to make sulfur dioxide. The sulfur dioxide is then further combusted in oxygen, in the presence of a **catalyst**, to make sulfur trioxide, which then reacts with water to produce sulfuric acid. The final chemical reaction step of the procedure is shown below:

$$\text{sulfur trioxide} + \text{water} \rightarrow \text{sulfuric acid}$$

$$SO_3(g) + H_2O(\ell) \rightarrow H_2SO_4(aq)$$

Quick check 5.12

1. **State** two uses for sulfuric acid.
2. **Name** the reactants used in the final reaction, which produces sulfuric acid.

Making thinking visible 5.1

Chalk talk: useful chemical reactions

Chemical reactions are used to make useful products that humans use every day.

1. What ideas and examples come to mind when you read the above statement?
2. Share your ideas with a partner.
3. Which of your ideas connect with your partner's responses?
4. What questions do you have after considering your partner's responses?

The *Chalk talk* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Section 5.3 questions

Remembering

1. **Recall** the products of the following reactions.
   a) acid + metal →
   b) acid + base →
   c) acid + carbonate →
   d) acid + hydrogen carbonate →

Understanding

2. **State** the pH range of an acid and a base.
3. **Recall** the two rules when naming a salt.
4. **State** the pH of a neutral solution.

Applying

5. During an experiment to show that a neutral solution is formed when acids and bases react, Martin used equal volumes of sodium hydroxide (base) and hydrochloric acid. However, the solution after mixing was not neutral. **Explain** how this could have happened.

Analysing

6. **Compare** acid–base reactions with acid–metal reactions.
7. **Classify** the following equations as acid–base, acid–carbonate or acid–metal reactions.
   a) Produces a salt and water as products without production of carbon dioxide gas
   b) Produces a gas that can be identified by the squeaky pop test
   c) Nitric acid + sodium → sodium nitrate + hydrogen
   d) Produces a gas that turns limewater milky
   e) Is an example of a neutralisation reaction
   f) Forms a salt

Evaluating

8. **Predict** which of the following reactions will not produce a salt.
   a) Potassium hydroxide + hydrochloric acid
   b) Iron + sulfuric acid
   c) Platinum + hydrochloric acid
   d) Sodium carbonate + nitric acid
   e) Methane + oxygen
9. **Construct** word equations for the following scenarios.
   a) Magnesium hydroxide is added to nitric acid in a neutralisation reaction to form magnesium nitrate and water.
   b) Hydrochloric acid and calcium carbonate are mixed together.
   c) A reaction forms the products barium chloride and hydrogen gas.
10. Heartburn is caused by acid from the stomach entering the oesophagus. **Justify** the use of antacids to alleviate heartburn pain.

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5.4 Rate of a chemical reaction

Learning goals

At the end of this section, I will be able to:

1. Calculate the reaction rate of a chemical reaction.
2. Name and explain the factors that affect rates of reactions.
3. Define the role of a catalyst in a chemical reaction.

Reaction rate

reaction rate the quantity of reactant or product used up or made per unit of time; how quickly the reaction progresses

surface area the area of the outer part or surface of an object

How quickly a reaction progresses towards completion is described by the term **reaction rate**. The reaction rate for a chemical reaction can be calculated by measuring the quantity of a reactant used or the quantity of product formed over time.

$$\text{reaction rate} = \frac{\text{quantity of reactant used up}}{\text{time}}$$

$$\text{reaction rate} = \frac{\text{quantity of product formed}}{\text{time}}$$

The quantity of a reactant or product can be measured by the mass (in grams) or volume (in millilitres), and the time should be measured in units of seconds. Therefore, the units for rate of reaction may usually be given as g s^{-1} or mL s^{-1}. In some cases, when a quantity of a reactant or product has not been measured, a reaction rate can be calculated just from the time taken for the reaction to go to completion.

$$\text{reaction rate } (s^{-1}) = \frac{1}{\text{time (s)}}$$

In any case, the faster a product forms, a reactant is used up or the reaction goes to completion, the greater the rate of reaction.

VIDEO Monitoring reaction rates

Practical 5.6

Monitoring reaction rates

Be careful
Wear appropriate personal protective equipment.

Aim

To determine how the surface area of zinc affects the rate of reaction with nitric acid, by using the upturned measuring cylinder technique

Prior understanding

Although you are changing the mass of zinc in this experiment, you are actually changing the **surface area** of the metal. In this experiment, the nitric acid is in excess relative to each of the masses of zinc. That is, there will always be more than enough nitric acid to completely react with all of the zinc. So, by increasing the mass of zinc, you are effectively increasing the surface area. By measuring the volume of gas produced after one minute, the effect of increasing the surface area of zinc on the reaction rate can be determined.

continued ...

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Materials

- zinc powder
- 2 mol L^{-1} nitric acid
- 25 mL measuring cylinder
- 50 mL measuring cylinder
- 250 mL conical flask
- large bowl or container
- stopper and delivery tube
- weighing boat
- bosshead and clamp
- electronic balance
- stopwatch

Planning

Write a hypothesis for your investigation regarding the effect that the mass of zinc will have on the rate of the reaction.

Method

1. Copy the results table into your science book.
2. Half-fill the large bowl or container with water.
3. Fill a 50 mL measuring cylinder with water and carefully invert it in the large bowl of water. Do not lose any water from the measuring cylinder. Try to remove as much air as possible from the measuring cylinder.
4. Clamp the measuring cylinder in place using a bosshead and clamp.
5. Using the 25 mL measuring cylinder, measure 20 mL of 2 mol L^{-1} nitric acid and pour the acid into the conical flask.
6. Using the electronic balance, measure 1.00 g of zinc powder into a weighing boat.
7. Set up the delivery tube so the end without the stopper runs underneath and into the upturned measuring cylinder (see Figure 5.25 to help you).
8. Pour the zinc powder into the conical flask containing the acid. At the same time, put the stopper on top of the flask and start the stopwatch.
9. After one minute, record the volume of water displaced from the measuring cylinder. This is the same as the volume of gas produced.
10. Repeat once more with the same mass of zinc powder.
11. Repeat the steps for the other masses of zinc powder.

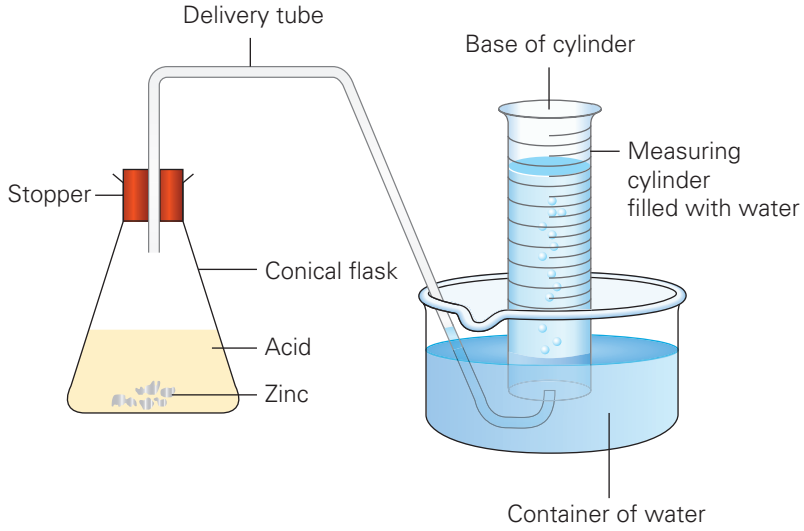

Figure 5.25 Diagram showing how to set up an upturned measuring cylinder to monitor reaction rate

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Results

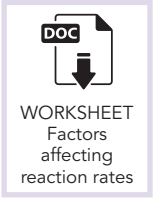
Mass of zinc (g)	Volume of gas collected after 1 minute (mL)		
	Trial 1	Trial 2	Mean
1.00			
1.50			
2.00			
2.50			

Discussion

1. List the independent and dependent variables in this investigation.
2. State two controlled variables.
3. Plot a graph with mass on the horizontal axis and volume of gas on the vertical axis.
4. What does your graph tell you about the relationship between the mass (that is, surface area) of zinc and reaction rate?
5. Write a balanced chemical equation with state symbols for the reaction between zinc metal (Zn) and nitric acid (HNO_3) to form zinc nitrate ($Zn(NO_3)_2$) and hydrogen (H_2).
6. List other methods you could have used to monitor the rate of this reaction.

Conclusion

1. Make a claim about the effect of the surface area of zinc on the rate of the reaction in this experiment.
2. Support your statement by using the data you gathered and include potential sources of error.
3. Explain how the data supports your statement.



WORKSHEET Factors affecting reaction rates

Factors that affect the rate of reaction

In the chemical manufacturing industry, it is important to know how to change the reaction rate of chemical reactions to ensure the most efficient, cost-effective and time-effective method is being used.

collisions the violent coming together of two or more particles; a requirement for a chemical reaction to occur

activation energy the minimum collision energy required to break and form bonds

For a chemical reaction to occur, reactant particles must collide with one another to cause bonds to break and new bonds to form. However, not all **collisions** are 'successful' in forming new products. This is because bonds will only break if the reactant particles collide with correct orientation and with at least a certain level of energy, called the **activation energy**, which is unique to each chemical reaction. The activation energy is the minimum energy required to break chemical bonds in the reactants so they are able to form new bonds and make the products. To increase the rate of reaction, it is important to increase the frequency of collisions and/or increase the proportion of particles that reach the activation energy for a successful collision to occur. Six factors can affect chemical reactions in these ways, and they will be explored here.

Quick check 5.13

1. **State** two requirements for a successful chemical reaction.
2. **Define** the term 'activation energy'.

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Figure 5.26 Industrial chemical plants rely on knowledge of reaction rates to produce maximum amounts of product in minimal amounts of time.

Concentration

WORKSHEET
How does concentration affect reaction rate?

The concentration of reactants in a solution is a measure of the number of particles per unit of volume. As an example, concentration can be measured in units of g L^{-1} or mg L^{-1}. However, it is commonly measured as moles per litre (mol L^{-1}), where moles are a quantitative measure of the amount of solute. You may also see these units written as a capital M, which is the same as mol L^{-1}. You will learn more about the unit of moles in Section 5.5.

A solution which contains a high number of solute particles within a given volume of solvent is called a **concentrated solution**. In contrast, a solution which contains a low number of solute particles within a given volume of solvent is called a **dilute solution**. Increasing the concentration of a solution means that there are more particles per unit of volume.

concentrated solution
a solution which contains a relatively large amount of solute compared to solvent

dilute solution
a solution which contains a relatively small amount of solute compared to solvent

If the concentration of a solution is increased, the particles are more likely to collide in each second; there will be more frequent collisions and the reaction rate will increase.

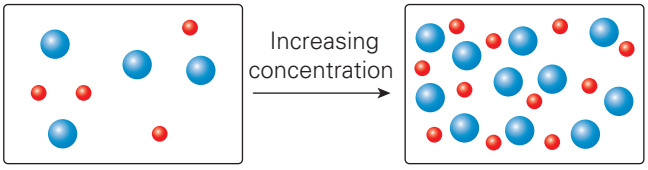

Figure 5.27 Increasing the concentration of a solution increases the number of particles within the same volume, increasing the frequency of potential collisions between particles.

Although increasing the concentration increases the frequency of collisions, it does not affect the activation energy. Particles still need to collide with the same activation energy for collisions to be successful. However, as collisions are occurring more frequently, successful collisions will also occur more frequently.

Quick check 5.14

1. **Decide** whether the following statements are true or false. If false, state a reason why.
   a) A dilute solution contains few reactant particles in a given volume.
   b) Increasing the concentration of a reactant decreases the activation energy needed for collisions.

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VIDEO Concentration and reaction rate

Practical 5.7

Concentration and reaction rate

Be careful

Wear appropriate personal protective equipment.
This experiment must be performed in a fume hood. Do not breathe in fumes when making observations.

Aim

To determine how changing the concentration of sodium thiosulfate affects the rate of reaction with hydrochloric acid

Materials

- 2 mol L^{-1} hydrochloric acid
- 0.15 mol L^{-1} sodium thiosulfate solution
- 250 mL conical flask
- 10 mL measuring cylinder
- 50 mL measuring cylinder × 2
- stirring rod
- piece of white paper
- black marker pen
- stopwatch

Planning

Construct a hypothesis regarding how the sodium thiosulfate concentration will affect the reaction rate.

Method

1. Copy the results table into your science book.
2. Using the black marker, draw a large 'X' on the white paper.
3. Using a 50 mL measuring cylinder, measure 50 mL of sodium thiosulfate and pour it into the 250 mL conical flask. In the fume hood, centre the conical flask on the black cross (see Figure 5.28).

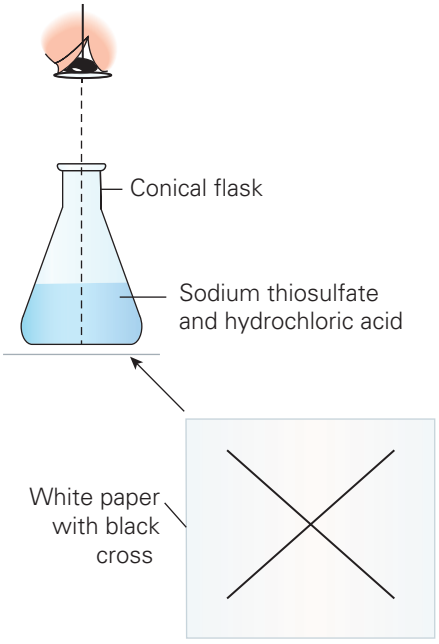

Figure 5.28 Diagram of centring the 'X' under the conical flask

4. Using the 10 mL measuring cylinder, measure 5 mL of hydrochloric acid.
5. Pour the acid into the conical flask, stir with a stirring rod and start the stopwatch.
6. Stop timing when the cross is no longer visible and record the time in your results table.
7. Follow your teacher's instructions for disposing of the reaction mixture.
8. Repeat steps 3–7 for each concentration of sodium thiosulfate in the results table. Remember to check the results table for the volume of sodium thiosulfate and water required for each concentration. The concentration of the sodium thiosulfate you have been supplied with is 0.15 mol L^{-1}; adding water dilutes the solution.

Results

Concentration of sodium thiosulfate (mol L^{-1})	Volume of sodium thiosulfate (mL)	Volume of water (mL)	Time taken for cross to disappear (s)	Reaction rate (s^{-1}) $\frac{1}{\text{time (s)}}$
0.15	50	0		
0.12	40	10		
0.09	30	20		
0.06	20	30		
0.03	10	40		

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Data processing

1. Work out and write the results for the relative rate of the reaction in the final column of your results table by calculating: $\frac{1}{\text{time (s)}}$
2. Plot a graph of concentration (horizontal axis) versus rate (vertical axis).

Discussion

1. Using your graph, describe how increasing the concentration of sodium thiosulfate affects the rate of this chemical reaction.
2. Explain why increasing the concentration of a reactant normally increases the rate of reaction.
3. Explain why the disappearing cross method was suitable for this reaction, using the equation below:

$$Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow S(s) + SO_2(g) + 2NaC\ell(aq) + H_2O(I)$$

Conclusion

1. Make a claim about the concentration of sodium thiosulfate and the effect this has on the rate of reaction based on this experiment.
2. Support your statement by referring to the data you gathered.
3. State whether your hypothesis was supported or not supported.

Pressure

To increase the **pressure** of gaseous particles, you can increase the number of particles and/or decrease the volume of the container.

pressure the force produced by collisions of gas particles per unit area of the container walls

Gaseous particles under high pressure are more likely to collide more frequently as there are more particles per unit of volume.

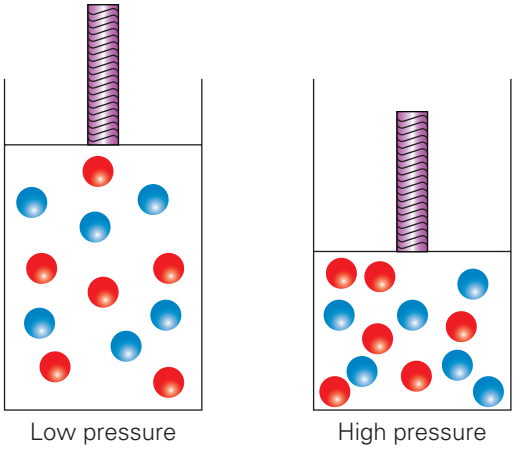

Figure 5.29 Reducing the volume of the container increases the pressure of gaseous molecules.

Therefore, increasing the pressure increases the rate of reaction. This can only happen if one of the reactants is a gas because solid and liquid particles are nearly impossible to compress. It is a bit like the comparison between a class of 30 students running around a sports hall with the same class running around in a classroom. The smaller space increases the pressure, meaning they are more likely to collide. The energy with which the students collide, however, is not affected.

Quick check 5.15

1. **Describe** why increasing the pressure of a solid and liquid does not affect reaction rate.
2. **Describe** a way in which the pressure of gas in a container can be increased.

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Surface area

When solids react, only the particles on the surface are in contact with particles of the other reactant when they collide. By making a solid smaller, by cutting it into pieces or grinding it into a powder, the surface area is increased and more particles are exposed to possible collisions. Imagine a loaf of bread: when its surface area is increased after it has been cut into slices, there is a greater area of the bread exposed to the air, so it dries out or becomes stale more quickly.

Increasing the surface area of a solid will cause the reaction rate to increase. This is because there are more particles exposed to the reaction, increasing the frequency of collisions and, by extension, the frequency of successful collisions. However, just like increasing the concentration, the energy with which the particles collide is not affected, so the proportion of successful collisions does not change.

Figure 5.30 Cutting bread into slices increases its surface area.

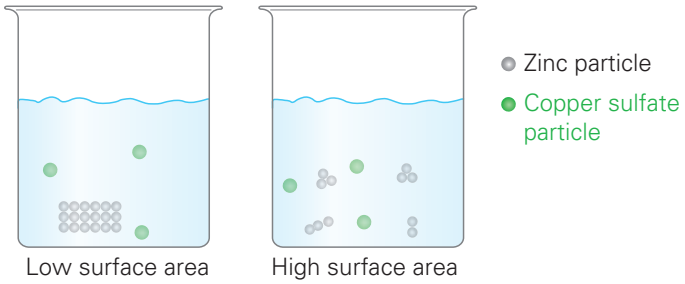

Figure 5.31 To increase the surface area of a solid reactant, cut it into smaller pieces or grind it into a powder.

Did you know? 5.3

Swallow, don't crush

Figure 5.32 If swallowing tablets is difficult, it may be worthwhile asking a pharmacist whether the medicine comes in other forms.

The pharmaceutical industry manufactures a wide variety of medicines through chemical reactions to produce a specific chemical to help an immune response or reduce pain. Often pharmaceutical medicines are sold in tablet form and are meant to be swallowed in that form – not crushed! The chemicals in the tablets can react with stomach acid to release the active ingredients into the bloodstream in a controlled fashion. However, if the tablet is crushed, the surface area of the reactant is increased, and the reaction in the stomach becomes much faster and less controlled. Therefore, there is a possibility of overdosing, or other side effects may occur, as the medicine has been released into the body too quickly. Moreover, it might also render the medicine less effective. Pharmaceuticals in tablet form are designed to both give you relief from illness and provide the medicine in the right amount of time.

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Quick check 5.16

1. **List** two ways by which the surface area of a solid can be increased.
2. A chemical reaction contains two different gaseous reactants. **Justify** whether increasing their surface area is a reasonable strategy to increase the reaction rate.
3. **Explain** why increasing the surface area of a reactant increases the reaction rate.

Practical 5.8

Surface area and reaction rate

Be careful

Risk of acid burns. Wear appropriate personal protective equipment. Wear safety glasses at all times. Do not consume food items.

Aim

To investigate how changing the surface area affects reaction rate

Prior understanding

Rhubarb contains oxalic acid, which will react with pink-coloured acidified potassium permanganate to form pale pink manganese(II) ions. This provides an ideal end point for measuring the rate of reaction.

VIDEO
Surface area and reaction rate

Materials

- 250 mL measuring cylinder
- 50 mL measuring cylinder
- 300 mL beaker
- 80 mL beakers × 9
- potassium permanganate crystals
- 1 mol L^{-1} sulfuric acid
- white tile
- rhubarb stalks with leaves removed
- cutting tile
- knife
- stopwatch
- tweezers

Planning

1. Identify the independent variable from the information in the aim and describe the different groups that will be set up for the experiment.
2. Define the dependent variable and how it will be measured.
3. Identify and list the controlled variables to be monitored. For each variable, you must define the property that will be measured (numerically if possible) to ensure they are not changing throughout the experiment – for example, temperature (to be maintained at 25°C).
4. Develop a hypothesis by predicting how a change in the independent variable will affect the dependent variable.
5. Write a risk assessment for this investigation.
6. Create a results table that will allow you to collect sufficient and relevant raw data, in addition to calculating the mean and uncertainty.

Method

Part 1: Prepare the potassium permanganate solution

1. Using a 250 mL measuring cylinder, measure 150 mL of 1 mol L^{-1} sulfuric acid, and pour into a 300 mL beaker.
2. Add a small pinch of potassium permanganate crystals to the beaker and stir well.
3. Add another 150 mL of 1 mol L^{-1} sulfuric acid to this solution. The solution will turn a light purple colour.

Part 2: Prepare the rhubarb

1. Cut nine identical lengths of rhubarb (about 3 cm long), ensuring they are as uniform as possible. You may need to use your knife to create straight edges and remove any excess.

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2. Take three of the lengths and calculate the approximate total surface area (TSA) of one of these lengths by using the calculation in Figure 5.33. These will be your 'low' -surface-area rhubarb.

Figure 5.33 Low-, medium- and high-surface-area rhubarb pieces

3. Take another three of the lengths and cut them each in half. Calculate the total surface area for the two halves. This will be your 'medium' -surface-area rhubarb.
4. Take another three of the lengths and cut them into four even pieces. Again, calculate the total surface area for the four quarters. This will be your 'high' -surface-area rhubarb.

Part 3: Measure the reaction time

1. Using a 50 mL measuring cylinder, measure 30 mL of acidified potassium permanganate and pour into an 80 mL beaker and place the beaker on a white tile.
2. Using tweezers, add a piece of the low-surface-area rhubarb to the beaker. Be careful not to splash the acid.
3. Immediately start the stopwatch. Stir the solution until the purple colour disappears, then stop the timer. You may want to have a beaker of water next to the reaction beaker for a comparison.
4. Complete Part 3 steps 1–3 twice more with the other pieces of low-surface-area rhubarb.
5. Repeat steps 1–3 with the other samples. Remember that for your 'medium' surface area, you will need to add both halves to the beaker together. For your 'low' surface area, you need to add all four quarters.
6. Record your data in the table.

Results

1. Calculate the mean reaction rate for each rhubarb sample.
2. Draw a scatter plot to analyse the relationship between the numerical independent variable and its dependent variable.
3. Plot a graph and insert a copy below the results table in your science book.

Discussion

1. Describe any trends, patterns or relationships that are found in your results.
2. Use your graph to predict the value of the dependent variable if you were given rhubarb pieces that were halfway between the sizes of the medium-surface-area and high-surface-area groups.
3. Extrapolate your data to predict the value of the dependent variable if you were given rhubarb pieces that had been cut into eight pieces.

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4. How much variation was observed between the measurements of different student groups within the class?
5. Were other variables that could affect the validity of the results successfully controlled during the experiment?
6. Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

Conclusion

1. Make a claim about the relationship between surface area and reaction rate based on this experiment.
2. Support your statement using data you gathered.
3. State whether your hypothesis was supported or not supported.

Stirring (agitation)

Stirring or **agitating** a chemical reaction increases the reaction rate as it causes more frequent collisions of reactant particles. When a chemical reaction like the one in Figure 5.34 is left undisturbed, the product forms on the surface of the solid reactant, creating a barrier for any further reaction. As with increasing concentration and surface area, stirring a chemical reaction only increases the frequency of collisions and, by extension, the frequency of successful collisions. Stirring and agitation do not change the activation energy of the reaction and so do not affect the proportion of successful collisions.

agitating
stirring, swirling or shaking a mixture

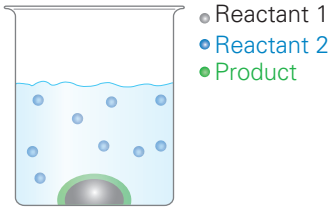

Figure 5.34 Stirring this reaction mixture would allow more of reactant 1 to come into contact with reactant 2.

Quick check 5.17

1. **Explain** why reaction rate increases when a mixture is agitated.

Temperature

When the temperature of a reaction system is increased, the rate of reaction also increases. The thermal energy added to the reaction is converted into kinetic (movement) energy, so on average the particles move at greater velocity. Particles are therefore more likely to collide more frequently, and because they move at greater velocities, they are also more likely to collide with more force. Thus, a greater proportion of particle collisions will reach the activation energy.

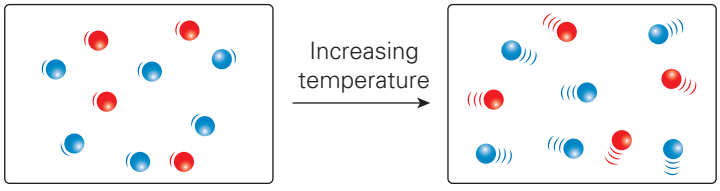

Figure 5.35 Increasing the temperature of a reaction increases the kinetic (movement) energy of the reactant particles, increasing the number of successful collisions.

Increasing the temperature of a chemical reaction increases the frequency of collisions and, by extension, the frequency of successful collisions. It also increases the proportion of collisions that are successful as more particles have the energy required to reach the activation energy.

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Quick check 5.18

1. **Identify** which one of the following types of energy particles convert into when heat is applied to a chemical reaction.
   - A) Chemical energy
   - B) Gravitational potential energy
   - C) Kinetic energy
   - D) Light energy
2. **Describe** why increasing the temperature of a chemical reaction increases the frequency of successful collisions.

Try this 5.2

Glowsticks

Get three glasses and fill one with ice-cold water, one with room-temperature water and one with hot water. Crack three glow sticks and add one to each glass. Observe which one glows the brightest.

Figure 5.36 A chemical reaction causes glow sticks to release light.

Practical 5.9

Temperature and reaction rate

Aim

To determine the effect of temperature on reaction rate

Materials

- 0.15 mol L^{-1} sodium thiosulfate solution
- 2 mol L^{-1} hydrochloric acid, initially at room temperature
- 10 mL measuring cylinder × 2
- beakers
- 250 mL conical flask × 3
- ice
- stopwatch
- thermometer
- water bath (heated to 50°C)
- stirring rod
- piece of white paper
- black marker pen

Be careful

Hydrochloric acid is corrosive. Heat the hydrochloric acid using a water bath only. Do not heat the acid directly with the Bunsen burner or hotplate. Do not seal the flask while reacting the acid and sodium thiosulfate. Wear appropriate personal protective equipment.

Wear safety glasses. Work under a fume hood.

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Planning

1. Create a research question that can be easily and safely investigated.
2. Write a hypothesis for your investigation regarding the effect of temperature on reaction rates.
3. Identify the independent and dependent variables in this investigation.
4. Give two controlled variables and state why they needed to be controlled.

Method

1. Copy the results table into your science book.
2. Using the 10 mL measuring cylinder, measure 10 mL of the sodium thiosulfate solution and 40 mL of water into a conical flask.
3. Measure 5 mL of dilute hydrochloric acid in a small measuring cylinder.
4. Put the conical flask over a piece of white paper with a cross drawn on it.
5. Add the acid to the conical flask, swirl the flask, place it back on the cross and start the stopwatch.
6. Record the temperature of the mixture in your results table.
7. Look down at the cross from above. When the cross disappears, stop the stopwatch and record the time taken for the cross to disappear.
8. Follow your teacher's instructions for disposing of the reaction mixture.
9. Repeat steps 2–8 another two times.
10. Repeat the entire experiment, but this time using ice to cool the sodium thiosulfate solution in the conical flask prior to adding the acid.
11. Again, repeat the entire experiment, but this time using a heated water bath to warm the sodium thiosulfate solution in the conical flask prior to adding the acid.

Results

Table showing time taken for cross to disappear (s)

Temperature (°C)	Time taken for cross to disappear (*s*)			
	Trial 1	Trial 2	Trial 3	Mean

Data processing

1. Calculate the mean time taken for the cross to disappear at each temperature.
2. Plot a graph of your results, including a line of best fit.

Discussion

1. Identify any patterns, trends or relationships in your results.
2. Explain why increasing the temperature of a reactant usually increases the rate of reaction.

Conclusion

1. Make a claim about the effect of temperature on reaction rate based on this experiment.
2. Support your statement by referring to the data you gathered.
3. State whether your hypothesis was supported or not supported and link your explanation to collision theory.

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Catalysts

A catalyst is a substance that can be added to a chemical reaction to increase the reaction rate. There is no net consumption of a catalyst, so it is present at the beginning and end of the reaction in the same quantity. For this reason, a catalyst is shown above the arrow in a chemical equation rather than on the reactant or product side of the equation.

$$\text{starch} \xrightarrow{\text{amylase}} \text{water + glucose}$$

Catalysts increase the reaction rate by providing an alternative reaction pathway with a lower activation energy for the reaction.

It is a bit like sheep jumping over a fence. The sheep are the reactant particles and the fence is the activation energy. If the fence (activation energy) is high, fewer sheep (particles) will reach the other side (fewer collisions will produce a successful reaction). On the other hand, if the farmer lowers the fence by adding a catalyst, more sheep will be able to jump the fence (there will be a greater proportion of successful collisions).

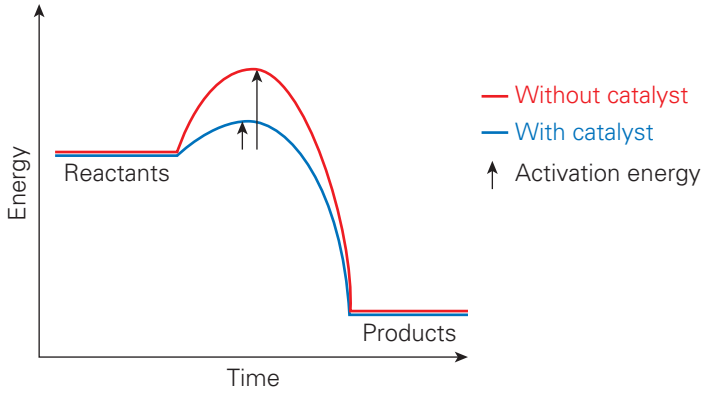

Figure 5.37 Adding a catalyst to a chemical reaction decreases the activation energy required, increasing the number of successful collisions and therefore the reaction rate.

For example, when you eat carbohydrate-rich foods, the starch molecules react with water and break down into glucose. The enzyme amylase, which is found in your saliva, acts to catalyse this reaction.

Figure 5.38 Some examples of carbohydrate-rich food

Quick check 5.19

1. **Define** the term 'catalyst'.
2. **Describe** how a catalyst increases the reaction rate.

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Practical 5.10

Catalysts and reaction rate

Be careful
Wear appropriate personal protective equipment.

Aim

To determine the most effective catalyst to decompose hydrogen peroxide

Materials

- 0.5 g manganese(IV) oxide
- 0.5 g iron(III) oxide
- 35% vol hydrogen peroxide solution
- 1 cm^3 piece of potato
- 1 cm^3 piece of liver
- 1 cm^3 piece of celery
- dishwashing detergent
- 250 mL measuring cylinders × 5
- plastic tray

Method

1. Copy the results table into your science book.
2. Line up the five measuring cylinders on the tray and add about 1 mL of dishwashing detergent to each measuring cylinder.
3. Add 25 mL of the 35% vol hydrogen peroxide to each measuring cylinder.
4. Add the manganese(IV) oxide to one of the measuring cylinders and start the stopwatch.
5. Measure the height of the foam when it stops rising.
6. Rinse the measuring cylinder and repeat this method for two more trials.
7. Repeat steps 1–6 for each of the catalysts.

Results

Catalyst	Height of foam (cm)				Uncertainty of foam height $\frac{\text{max} - \text{min}}{2}$
	Trial 1	Trial 2	Trial 3	Mean	
Manganese(IV) oxide					
Iron(III) oxide					
Potato					
Liver					
Celery					

Processing data

1. Calculate the mean height of foam for each catalyst.
2. Calculate the uncertainty in your results.

Discussion

1. Identify the catalyst that was the *most* effective at decomposing the hydrogen peroxide. How did you know?
2. Identify the catalyst that was the *least* effective at decomposing the hydrogen peroxide. How did you know?
3. Write a balanced chemical equation, including state symbols, for the decomposition of hydrogen peroxide (H_2O_2) into water (H_2O) and oxygen (O_2).
4. One of the products produced, water or oxygen, relights a glowing splint. Identify this product.
5. Identify any limitations of your experiment.
6. Describe any changes you could make that would improve the reliability of your results.

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WORKSHEET Reactions: keyword review

A summary of changing reaction rates

Table 5.12 summarises how each factor discussed in this section influences the rate of a chemical reaction.

Factor affecting reaction rate	Effect on the frequency of collisions	Effect on proportion of successful collisions	Effect on rate
Increasing concentration of reactants	Increases	Not affected	Increased
Increasing pressure of gaseous reactants			
Increasing agitation (stirring)			
Increasing surface area of solid reactants			
Increasing temperature		Increased	
Adding a catalyst	Not affected		

Table 5.12 A summary of how each factor discussed affects reaction rate

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Section 5.4 review

Online quiz | Section questions | Teachers can assign tasks and track results

Section 5.4 questions

Remembering

1. **State** three factors that can affect the rate of a chemical reaction.
2. **State** whether the following statements are true or false. If false, state a reason why.
   a) Increasing the rate of stirring has no effect on the rate of reaction.
   b) Changing the surface area of liquid reactants will increase the reaction rate.
   c) Changing the pressure of a reaction mixture will only affect reactions containing gaseous reactants.
   d) Increasing the temperature of a reaction increases the frequency and energy of collisions.
3. **Define** the term 'collision'.
4. **Recall** the name of chemicals that are added to a chemical reaction to reduce the activation energy.

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5. a) **Identify** the two solutions in Figure 5.39 that have the same concentration.
   b) **Identify** if the solution in the remaining beaker is more concentrated or more dilute, giving reasons for your choice.

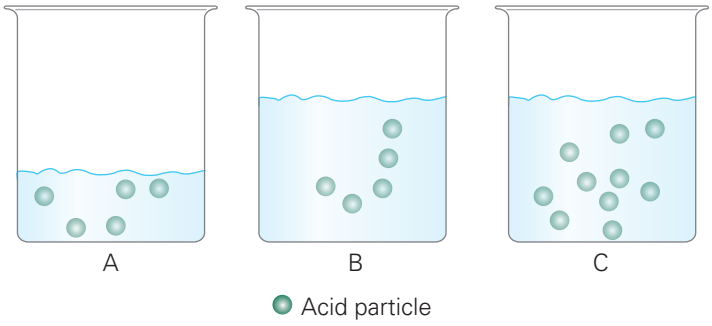

Figure 5.39 Solution concentrations

6. **Recall** the relationship between surface area and reaction rate.

Understanding

7. **Summarise** the requirements for a chemical reaction to occur.
8. **Summarise** the relationship between temperature and reaction rate.
9. Custard powder can explode when thrown into the air in the presence of a spark, but not when it is tightly packed in a container. **Explain** why.
10. Scientists often use magnetic stirrers to stir chemical reactions. **Explain** why this continuous stirring increases the rate of reaction.

Applying

11. **Contrast** a dilute solution and a concentrated solution.

Analysing

12. Children are advised to take fewer tablets than adults. **Propose** which factor affecting reaction rate is influencing this advice.
13. The chemical reaction that occurs when you bake cake mixture requires a large amount of heat for it to be successful. What can you **deduce** about the activation energy of this reaction?

Evaluating

14. A student conducted an experiment to determine how changing the concentration of hydrochloric acid affected the rate of reaction with sodium thiosulfate. They plotted a graph of their results, which can be seen in Figure 5.40. **Discuss** what can be concluded about the effect of increasing the concentration of acid in this reaction, giving detailed reasoning why this may be the case.
15. A student has two beakers of the same solution. They both have the same concentration. To increase the concentration of the solution, the student pours them into the same beaker. **Explain** whether the student has changed the concentration of the solution.

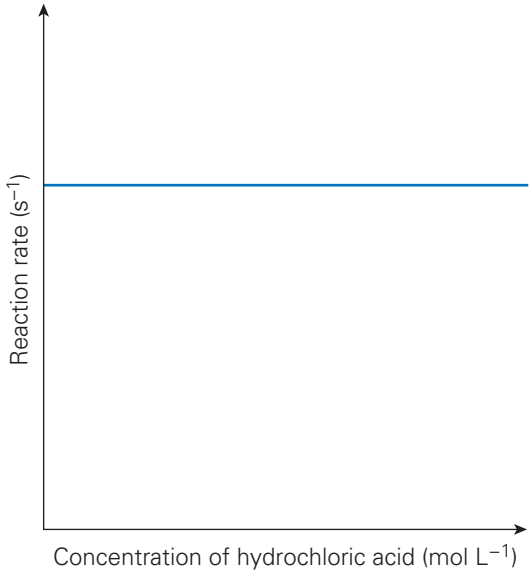

Figure 5.40 Graph of experiment

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5.5 Extension: Chemistry calculations

WORKSHEET
The Avogadro constant

Learning goals

At the end of this section, I will be able to:

1. Define the Avogadro constant.
2. Calculate the molar mass for an atom or compound.
3. Use the mole equation to solve problems including moles and mass.

In order to measure the efficiency of chemical reactions, scientists need to know how many particles are colliding and reacting in the chemical reaction. Take the following chemical reaction, for example:

$$2H_2 + O_2 \rightarrow 2H_2O$$

By analysing the coefficients of the chemical species, we know that *two* hydrogen molecules will react with *one* oxygen molecule to produce *two* water molecules. However, it will be very difficult to measure exactly two hydrogen molecules and one oxygen molecule to complete this reaction.

In fact, it will also be difficult on a larger scale to measure out two million hydrogen molecules and one million oxygen molecules. Scientists need an easier way to measure specific quantities of reacting particles.

The mole

To make this next concept simpler, imagine that you have a bag of rice grains and you measure *one* cup of rice grains in a measuring cup. A measuring cup might contain 8612 rice grains; however, a recipe will not tell you to measure 8612 rice grains, but instead to measure *one* cup of rice. This makes measuring rice a lot easier than counting individual rice grains 8612 times!

Figure 5.41 Imagine if recipes required you to count individual grains of rice!

elementary entity
a small particle such as an atom, compound, molecule or ion

mole
6.022×10^{23} elementary entities

Now let us treat **elementary entities** (N) as rice grains and one cup as a **mole** (n). Elementary entities can include small particles such as atoms, compounds, molecules and ions. One mole contains 6.022×10^{23} of these elementary entities, also known as the Avogadro constant (N_A).

Did you know? 5.4

Amadeo Avogadro

The number of elementary entities in a mole, 6.022×10^{23}, is also known as the Avogadro constant, N_A, named after the Italian scientist Amadeo Avogadro. His work in the early 1800s on the number of atoms in a given volume of gas was an important foundation for the mole concept, which would be defined later that century. Another scientist, Jean Perrin, named the constant after Avogadro in the early 1900s to celebrate his early influence on this field of chemistry. In 2019, the Avogadro constant was updated to be exactly $6.02214076 \times 10^{23}$ elementary entities. However, for simplicity we will use the number 6.022×10^{23} in our calculations.

Figure 5.42 Amadeo Avogadro was born in 1776 in Turin, Italy.

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Therefore, if a scientist were to now measure one mole of oxygen gas (O_2), they would have 6.022×10^{23} molecules to be exact, just as one cup of rice would contain 8612 rice grains in the previous example.

This relationship between the mole and the Avogadro constant can be expressed mathematically:

$$\text{Number of moles} = \frac{\text{number of elementary entities}}{\text{Avogadro constant}}$$

Or

$$n\,(\text{mol}) = \frac{N}{N_A\,(\text{mol}^{-1})}$$

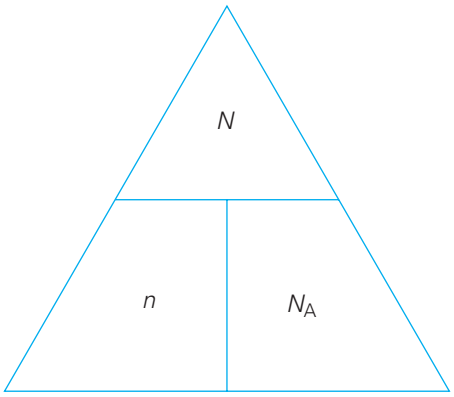

Figure 5.43 The formula triangle for the number of elementary entities. To use the formula triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

Worked example 5.1

1. Calculate the number of moles of gold atoms if there are 3.01×10^{24} atoms.
2. Calculate the number of molecules of hydrogen gas (H_2O) in 0.5 moles.

Working	Explanation
1. Substitute values into the equation and solve.	
$n = \frac{N}{N_A}$ $\frac{3.01 \times 10^{24}\ \text{atoms}}{6.022 \times 10^{23}\ \text{atoms mol}^{-1}} = 5\ \text{mol}$	To solve for the number of moles, substitute the number of atoms as the number of elementary entities, and the Avogadro constant, 6.022×10^{23}, for N_A.
2. Rearrange the equation to solve for the number of molecules.	
$N = n \times N_A$ $= 0.5\ \text{mol} \times 6.022 \times 10^{23}\ \text{mol}^{-1}$ $= 3.011 \times 10^{23}$ elementary entities or molecules	Rearrange the equation to solve for the number of molecules (elementary entities). Substitute the number of moles and the Avogadro constant to solve.

Quick check 5.20

1. **Identify** the number of hydrogen molecules in 1 mole.
2. **Identify** the number of hydrogen molecules in 2 moles.
3. **Calculate** the number of water molecules in 3.5 moles.
4. **Identify** the number of moles of sodium in 1.806×10^{23} atoms of sodium.

The mole is a useful concept. However, we still have not answered the question: How can we measure a mole of a chemical species? How can we measure 6.022×10^{23} molecules, and where did the Avogadro constant come from?

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Molar mass

relative atomic mass
the mass of the number of protons and average number of neutrons in an atom relative to carbon-12

molar mass
the mass of one mole of an elementary entity

In the early 1900s, a scientist, Jean Perrin, set out to answer the question of how many molecules of oxygen gas (O_2) were in exactly 32 grams of the gas. From the periodic table, we can see that the atomic number of oxygen is 8 – that is also the number of protons in the nucleus of an oxygen atom. The periodic table also shows a number of **relative atomic mass**, which is the mass of the number of protons plus the average number of neutrons in the nucleus (relative to an atom of carbon-12). Many periodic tables will show this number to be 15.9994 for oxygen, and in this example, we will round that number to 16.00.

A molecule of oxygen gas (O_2) has two oxygen atoms, and therefore, the overall relative atomic mass of this molecule can be calculated as 16 + 16 = 32. Thus, Perrin wanted to know how many molecules were present in a measurable mass of 32 grams – a number similar to the relative atomic mass of oxygen gas, which is 32. This number of molecules was found to be 6.022×10^{23} molecules. Perrin then named it the Avogadro constant, the number of elementary entities in a mole.

Therefore, if 32 grams of oxygen gas contains 6.022×10^{23} molecules, and one mole of oxygen gas contains 6.022×10^{23} molecules, then 32 grams of oxygen gas contains one mole of oxygen gas. This concept is known as the **molar mass** (M), and the molar mass of a molecule of oxygen gas can be determined from the relative atomic mass provided on the periodic table.

For example: $M(O_2) = 32\ g\ mol^{-1}$

In other words, there are 32 grams per mole of oxygen gas.

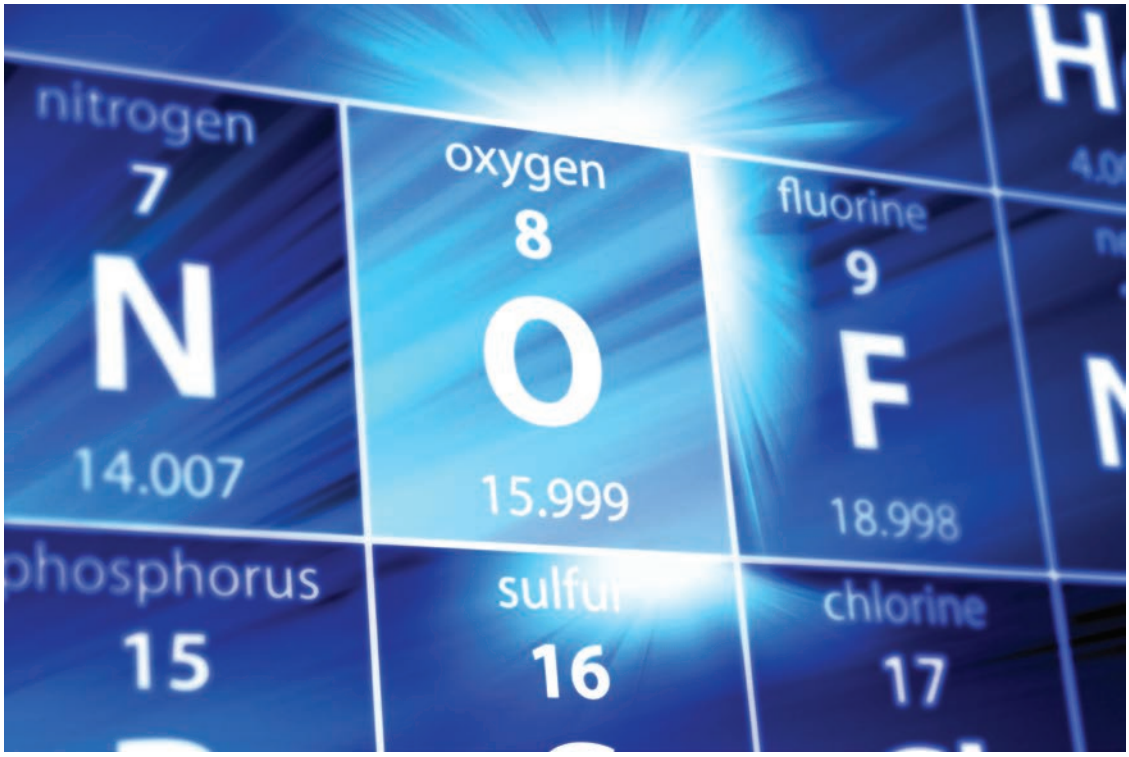

Figure 5.44 The relative atomic mass of oxygen on the periodic table

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The Avogadro constant and molar mass can be used to communicate quantities of any atom, molecule or compound by referring to the relative atomic masses shown on the periodic table.

Worked example 5.2

1. Calculate the molar mass of carbon.
2. Calculate the molar mass of water.
3. Calculate the molar mass of sodium chloride.

Working	Explanation
1. Molar mass of a single atom	
Relative atomic mass of C = 12.01 M(C) = 12.01 g mol^{-1}	For a single atom, the molar mass is the same as the relative atomic mass shown on the periodic table, with units of g mol^{-1}.
2. Molar mass of a molecule	
Relative atomic mass of O = 16.00 Relative atomic mass of H = 1.01 $M(H_2O)$ = 1.01 + 1.01 + 16.00 = 18.02 g mol^{-1}	For a molecule, add all relative atomic masses from the periodic table with units of g mol^{-1}. Remember, there are two hydrogen atoms per H_2O molecule.
3. Molar mass of a compound	
Relative atomic mass of Na = 22.99 Relative atomic mass of Cℓ = 35.45 M(NaCℓ) = 22.99 + 35.45 = 58.44 g mol^{-1}	For a compound, add all relative atomic masses from the periodic table with units of g mol^{-1}.

Quick check 5.21

1. **Calculate** the molar mass of nitrogen gas (N_2).
2. **Calculate** the molar mass of elemental gold (Au).
3. **Calculate** the molar mass of ammonia (NH_3).
4. **Calculate** the molar mass of calcium phosphate ($Ca_3(PO_4)_2$).

The mole equation

The mole, the Avogadro constant and the molar mass can now be brought together to create an equation relating the measurable mass of a substance to the number of moles or even elementary entities. This is known as the mole equation:

$$\text{Number of moles} = \frac{\text{mass}}{\text{molar mass}}$$

Or

$$n\ (\text{mol}) = \frac{m(g)}{M\ (\text{g mol}^{-1})}$$

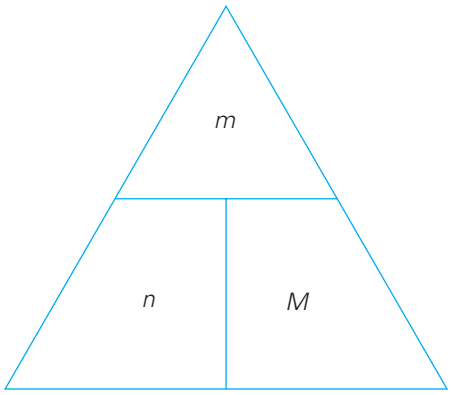
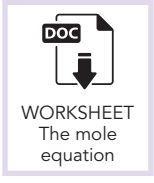


Figure 5.45 The formula triangle for molar mass. To use the formula triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.



Using this equation, scientists can calculate a measurable mass of chemical substance for a given number of moles of that substance.

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Worked example 5.3

1. Calculate the number of moles of silver (Ag) in 0.25 g of metallic silver.
2. Calculate the number of moles of water (H_2O) in 5 g of the liquid.
3. Calculate the mass of 1.35 mol of barium bromide ($BaBr_2$).

Working	Explanation
1. Number of moles of Ag	
m = 0.25 g M(Ag) = 107.87 g mol^{-1}	Identify the mass and molar mass of atomic silver. You need to refer to the periodic table for the molar masses.
$n = \frac{m}{M} = \frac{0.25\text{ g}}{107.84\text{ g mol}^{-1}} = 0.0023\text{ mol}$	Substitute known values of mass and molar mass (from the periodic table) and solve for moles.
2. Number of moles of H_2O	
m = 5 g M(O) = 16.00 g mol^{-1} M(H) = 1.01 g mol^{-1} $M(H_2O)$ = (2 × 1.01) + 16.00 = 18.02 g mol^{-1}	Identify the mass and molar mass of H_2O. (Add the molar mass values of one atom of oxygen and two atoms of hydrogen from the periodic table.)
$n = \frac{m}{M} = \frac{5\text{ g}}{18.02\text{ g mol}^{-1}} = 0.277\text{ mol}$	Substitute known values of mass and molar mass and solve for the number of moles.
3. Mass of $BaBr_2$	
n = 1.35 mol M(Ba) = 137.33 g mol^{-1} M(Br) = 79.90 g mol^{-1} $M(BaBr_2)$ = 137.33 + (2 × 79.90) = 297.13 g mol^{-1}	Identify the number of moles, n, and molar mass, M, of $BaBr_2$. (Add the molar mass values of one atom of barium and two atoms of bromine from the periodic table.)
$m = n \times M$ = 1.35 mol × 297.13 g mol^{-1} = 401.13 g	Rearrange the equation to solve for mass. Substitute known values of moles and molar mass.

Quick check 5.22

1. **Calculate** the number of moles in 1 g of hydrogen gas (H_2).
2. **Calculate** the mass of 15 mol of lithium metal (Li).
3. **Calculate** the molar mass of an unknown compound that has 2 mol of particles in 72.9 g.

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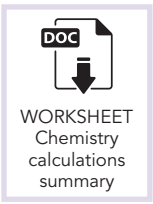
Bringing it all together



As we know, a given number of moles of a substance is directly related to the Avogadro constant and also the mass. We can therefore relate a mass to number of elementary entities.

See the two equations used in this chapter once more:

$$n\,(\text{mol}) = \frac{N}{N_A\,(\text{mol}^{-1})}$$

$$n\,(\text{mol}) = \frac{m(g)}{M\,(\text{g mol}^{-1})}$$

Worked example 5.4

1. Calculate the number of water molecules in 0.65 g of the liquid.
2. Calculate the mass of 1.138×10^{24} molecules of methane (CH_4).

Working	Explanation
1. Finding the number of molecules, given the mass	
$m = 0.65$ g $M = 18.02$ g mol^{-1} (see Worked example 5.2)	Identify the mass and molar mass.
$n = \frac{m}{M}$ $= \frac{0.65\text{ g}}{18.02\text{ g mol}^{-1}}$ $= 0.0361$ mol	Use the molar mass triangle. Substitute known values of mass and molar mass and solve for moles.
$N = n \times N_A$ $= 0.0361\text{ mol} \times 6.022 \times 10^{23}\text{ mol}^{-1}$ $= 2.17 \times 10^{22}$ elementary entities or molecules There are 2.17×10^{22} molecules of water in 0.65 g.	Use the moles and the Avogadro constant triangle to solve for the number of molecules.
2. Finding the mass, given the number of molecules	
$N = 1.138 \times 10^{24}$ molecules $N_A = 6.022 \times 10^{23}$ molecules mol^{-1}	Identify the number of molecules and the Avogadro constant.
$n = \frac{N}{N_A}$ $= \frac{1.138 \times 10^{24}\text{ molecules}}{6.022 \times 10^{23}\text{ molecules mol}^{-1}}$ $= 1.89$ mol	Use the moles and the Avogadro constant triangle. Substitute the known value of the number of molecules and the Avogadro constant and solve for moles.
$M(C) = 12.01$ g mol^{-1} $M(H) = 1.01$ g mol^{-1} $M(CH_4) = 12.01 + (4 \times 1.01) = 16.05$ g mol^{-1}	Calculate the molar mass.
$m = n \times M$ $= 1.89\text{ mol} \times 16.05\text{ g mol}^{-1}$ $= 30.33$ g	Use the moles and the molar mass triangle to solve for the mass.

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Section 5.5 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 5.5 questions

Remembering

1. **State** the number and units of the Avogadro constant.
2. **Define** the mole in relation to chemistry.

Understanding

3. **Describe** why the units of molar mass are g mol^{-1}. In your response, refer to the Avogadro constant.
4. **Calculate** the molar mass of carbon dioxide (CO_2).
5. **Calculate** the molar mass of ammonium sulfate ($(NH_4)_2SO_4$).
6. **Calculate** the molar mass of tryptophan ($C_{11}H_{12}N_2O_2$).

Applying

7. **Calculate** the number of moles of carbon monoxide (CO) present in 90.25 g.
8. **Calculate** the number of moles if 6.022×10^{22} atoms of platinum (Pt) are present.
9. **Calculate** the mass of 3.41 mol of ozone (O_3).
10. **Calculate** the mass of 0.999 mol of uranium oxide (UO_2).

Analysing

11. An unknown compound of 1.5 g was analysed to contain 1.048×10^{22} particles. Use this information to **explain** how to find the molar mass of the unknown compound, and determine this value.
12. The unknown compound in Question 11 was identified as hexane (C_6H_{14}). **Justify** that the molar mass that was determined in Question 11 matches that of this compound.

Evaluating

13. A sample of water (H_2O) was weighed, and a mass of 5.00 grams was recorded. **Justify** that the number of water molecules in the sample *can* be determined from this measurement.
14. For the same sample in Question 13, **justify** that the number of hydrogen atoms present in the sample *can* be determined.

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Chapter review

Chapter checklist

Success criteria		Linked questions
5.1	I can represent chemical reactions using word and balanced chemical equations.	8, 11
5.1	I can recal the correct use of state symbols in a chemical equation.	8
5.1	I can balance a chemical equation.	8
5.2	I can identify a reaction type and predict the products.	13, 15
5.2	I can identify the solubility of a salt.	
5.2	I can write balanced chemical equations for synthesis, decomposition, metal displacement and precipitation reactions.	8
5.3	I can explain the meaning of pH and the pH scale.	7
5.3	I can write balanced chemical equations for the three types of neutralisation reactions.	6, 20
5.4	I can calculate the reaction rate of a chemical reaction.	11
5.4	I can name and explain the factors that affect rates of reactions.	2
5.4	I can describe the role of a catalyst in a chemical reaction.	10

Extension

5.5	I can calculate the number of moles from a given mass or number of particles of substance.	Section 5.5 questions

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review

Review questions

Remembering

1. **Name** three diatomic elements on the periodic table.
2. **State** six factors that affect the rate of a reaction.
3. **Recall** the products of an acid reaction with the following.
   a) Metal
   b) Base
   c) Carbonate
4. **Recall** one factor which speeds up the rate of a chemical reaction solely by affecting the frequency of collisions.
5. **Recall** the relationship between reaction rate and the time a reaction takes to reach completion.
6. **Identify** why sulfuric acid is such an important chemical to the chemical industry.

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Understanding

7. **Explain** what a pH of 4 means with respect to acids and bases.
8. **Write** a balanced equation for the reaction of magnesium metal (Mg) and hydrochloric acid (HCℓ), showing state symbols.
9. **Describe** what is meant by a 'successful collision'.
10. **Explain** the effect a catalyst has on the rate of a chemical reaction.

Applying

11. **Represent** the following balanced equation as a word equation.

$$H_2SO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + CO_2 + H_2O$$

12. **Calculate** the rate of a reaction, in g s^{-1}, in which 1.5 grams of solid product was formed in 56 seconds.
13. **State** whether the following reactions are synthesis or decomposition reactions.
    a) $CuCO_3 \rightarrow CuO + CO_2$
    b) $H_2 + O_2 \rightarrow H_2O$

Analysing

14. **Analyse** the balanced equation to find a mistake.

$$4HNO_3(aq) + Cu(g) \rightarrow Cu(NO_3)_2(aq) + H_2O + 2NO_2(g)$$

15. **Write** a balanced equation for the outcome of the following displacement reactions.
    a) Iron(II) oxide + carbon
    b) Copper(II) nitrate + zinc
    c) Magnesium sulfate + zinc
    d) Gold + zinc nitrate
16. **Classify** the following metals as more or less reactive than iron.
    a) Potassium
    b) Gold
    c) Copper
    d) Zinc

Evaluating

17. **Write** a balanced equation, with state symbols, for the reaction of aqueous phosphoric acid and a solution of potassium carbonate.
18. **Write** a balanced equation, with state symbols, for the reaction of calcium solid and a solution of ethanoic acid.
19. The reaction of hydrogen gas and ethene (C_2H_4) produces ethane (C_2H_6) in the presence of a palladium (Pd) catalyst. **Write** a balanced equation for this chemical reaction.
20. **Discuss** the importance of our understanding of reaction rates for the chemical industry.

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Data questions

A group of chemistry students is measuring the rate of a reaction of magnesium metal and hydrochloric acid under different conditions. In three separate test tubes, the students add a strip of magnesium to 1 mol L^{-1} HCℓ, powdered magnesium to 1 mol L^{-1} HCℓ, and powdered magnesium in 2 mol L^{-1} HCℓ, respectively. The data points are presented in Figure 5.46. Note that the mass of magnesium used is the same for each reaction.

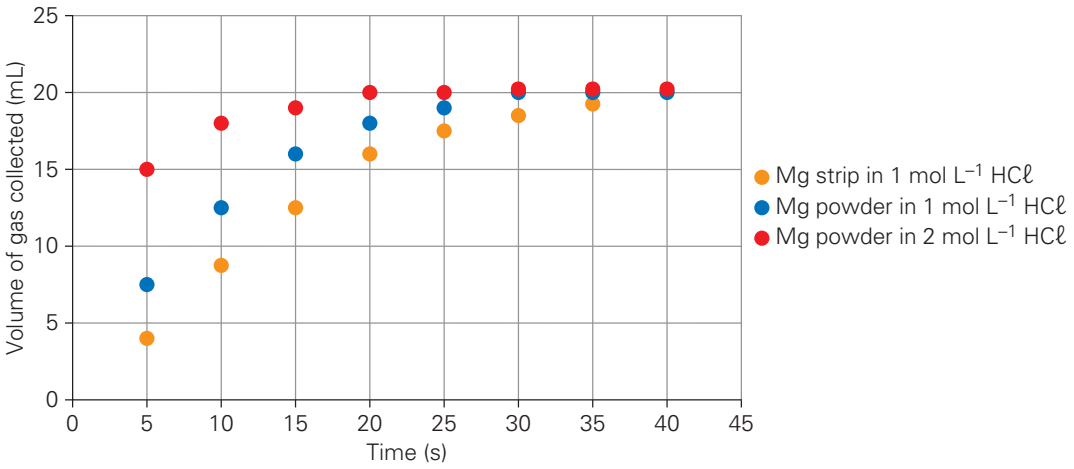

Figure 5.46 Volume of gas collected over time from reactions of magnesium metal and hydrochloric acid

1. **Identify** the conditions in which the reaction went to completion fastest.
2. **Calculate** the rate of the reaction (in mL s^{-1}) for the magnesium strip in 1 mol L^{-1} HCℓ from the time 0 to 40 seconds.
3. The rate of the reaction for the magnesium powder in 1 mol L^{-1} HCℓ is 0.67 mL s^{-1}. Use this information and your answer to Questions 1 and 2 to **determine** which reaction has the slowest reaction rate.
4. **Identify** the trend in the plot which is similar for all three experiments.
5. **Contrast** the effect of the magnesium surface area on the volume of gas produced and the rate of the reaction.
6. **Analyse** the data presented in Figure 5.46 for the three experiments. What would be the volume of gas collected for each experiment at 0 seconds (before reactants were mixed)?
7. A student has stated that when all magnesium and hydrochloric acid has reacted, the volume of gas produced will be 20 mL. **Justify** this conclusion with reference to the data in Figure 5.46.
8. **Extrapolate** the data for the magnesium strip in 1 mol L^{-1} HCℓ experiment and estimate the volume of gas produced after 120 seconds.
9. The students would like to run another experiment with the same mass of magnesium powder in 5 mol L^{-1} HCℓ. **Predict** (using Figure 5.46 as a template) how the data might be different in this experiment.

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STEM activity: Designing airbags

Background information

Airbags work on the principle of increasing the time of impact between two objects. In a car crash this could be the difference between life and death. A sensor is connected to an electrical circuit and, once activated, will send a signal that ignites the guanidinium nitrate ($CH_6N_4O_3$) within the airbag and releases nitrogen at high speed. Airbags are not without risk, though. Failures include burns from the explosive chemical reaction and injuries from the projectile velocity of the bag itself, which can reach 330 km h^{-1}.

DESIGN BRIEF

Design and create an airbag prototype that uses environmentally friendly chemicals and materials in its manufacture. The airbag will need to create gas rapidly to work effectively.

Activity instructions

In groups, you will design an airbag that uses a chemical reaction to produce a safe gas that fills the airbag space. Your design will incorporate features that would make your airbag safe through the whole chemical reaction and environmentally friendly for disposal. If you cannot source the materials you need, you can produce a model and state the chemical reaction.

Suggested materials

- various types of acid (e.g. vinegar)
- various types of bases (e.g. baking soda)
- beakers of various size
- measuring cylinder
- rubber tubing
- thermometer
- plastic bags
- stopwatch
- balloons
- various building materials

Figure 5.47 Car airbags after they have been deployed and then deflated

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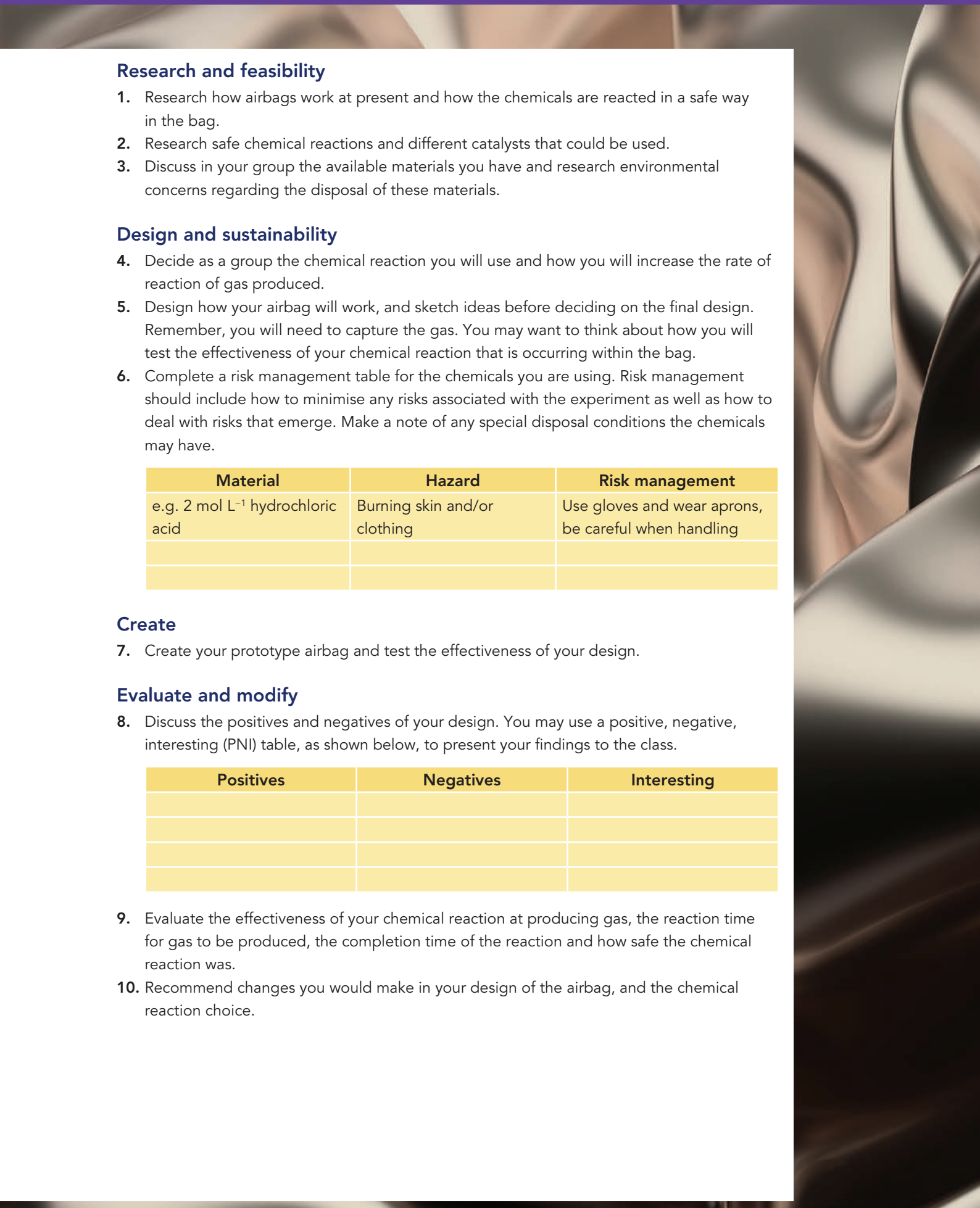

Research and feasibility

1. Research how airbags work at present and how the chemicals are reacted in a safe way in the bag.
2. Research safe chemical reactions and different catalysts that could be used.
3. Discuss in your group the available materials you have and research environmental concerns regarding the disposal of these materials.

Design and sustainability

4. Decide as a group the chemical reaction you will use and how you will increase the rate of reaction of gas produced.
5. Design how your airbag will work, and sketch ideas before deciding on the final design. Remember, you will need to capture the gas. You may want to think about how you will test the effectiveness of your chemical reaction that is occurring within the bag.
6. Complete a risk management table for the chemicals you are using. Risk management should include how to minimise any risks associated with the experiment as well as how to deal with risks that emerge. Make a note of any special disposal conditions the chemicals may have.

Material	Hazard	Risk management
e.g. 2 mol L^{-1} hydrochloric acid	Burning skin and/or clothing	Use gloves and wear aprons, be careful when handling

Create

7. Create your prototype airbag and test the effectiveness of your design.

Evaluate and modify

8. Discuss the positives and negatives of your design. You may use a positive, negative, interesting (PNI) table, as shown below, to present your findings to the class.

Positives	Negatives	Interesting

9. Evaluate the effectiveness of your chemical reaction at producing gas, the reaction time for gas to be produced, the completion time of the reaction and how safe the chemical reaction was.
10. Recommend changes you would make in your design of the airbag, and the chemical reaction choice.

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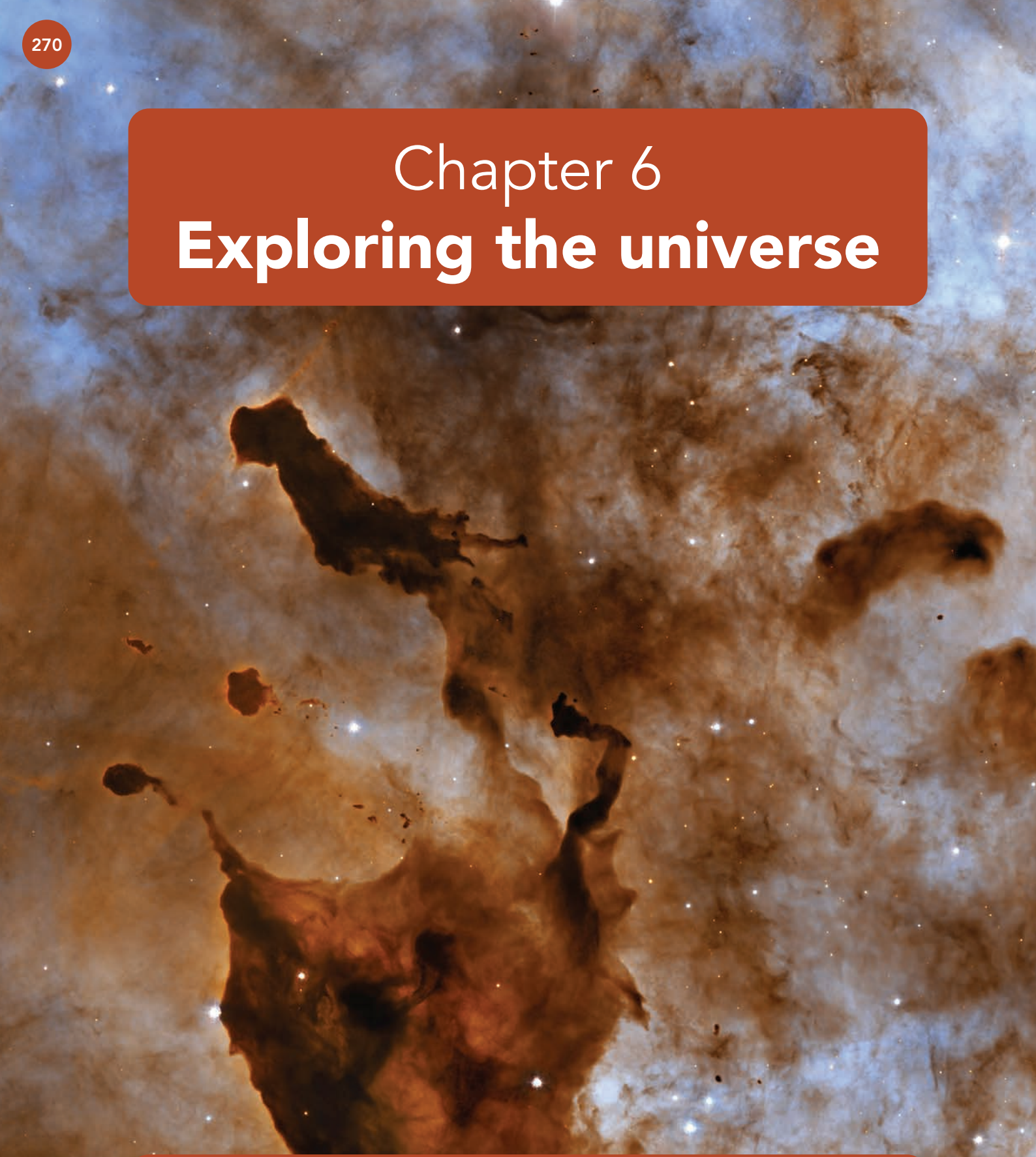
Chapter 6
Exploring the universe



Chapter introduction

Ranging from subatomic particles to the expanding universe, no other branch of science has the overall scope of astronomy. It has ancient origins and yet is still advancing. In this chapter, you will learn about our position in the universe, how the universe began and what it is made of. You will consider how stars evolve and the ways we use technology to observe and learn about space.

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Chapter map

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Curriculum content

Earth and space sciences	
The formation of stars, galaxies and solar systems has continued since the time of the Big Bang; stars have a life cycle determined by their mass	
• the life cycle of different types of stars	6.2
• the formation of the Milky Way Galaxy	6.3
• the nebular hypothesis for the formation of our solar system	6.4
Space exploration contributes to knowledge of the formation and evolution of the universe and Earth, as well as providing useful tools and technologies to improve our life on Earth	
• data gathered through space rover and probe missions is providing information about the geology and atmosphere of moons and other planets in our solar system	6.1
• data gathered through space exploration can be used to search for possible life beyond our solar system	6.1
• applications of space technology, including remote sensing of Earth, communication systems and scientific exploration	6.1
• importance of Australia's role in space exploration	6.1
• contribution of the Square Kilometre Array (SKA) to space exploration	6.1
• impact of space junk and satellites on future space exploration and Earth	6.1
• impact of low gravity on biological systems	6.1
Collaborating and applying	
Illustrate how advances in scientific understanding often rely on developments in technologies and engineering and technological and engineering advances are often linked to scientific discoveries	
• exploring how astronomer Vera Rubin's discovery of the existence of dark matter was validated	6.4
• exploring how the development of fast computers has made possible the analysis of radio astronomy signals and other data generated by major international science projects, such as the Event Horizon Telescope and the Square Kilometre Array (SKA)	6.1

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Glossary terms

absorption spectrum
arcsecond
astronomical unit
B–V colour index
baseline
Big Bang
black hole
blue shift
constellation
continuous spectrum
cosmic microwave background
Cultural Lore
dark energy
dark matter
Doppler effect
emission spectrum
epoch of recombination
exoplanet
galaxy
geocentric
Goldilocks zone
H–R diagram
heliocentric
Hubble's law
interferometry
light year
luminosity
main sequence
nebula
neutron star
nuclear fusion
observable universe
optical telescope
parallax
parsec
planetary nebula
plasma
radio telescope
recessional velocity
red giant
red shift
retrograde motion
singularity
spectral class
supernova
white dwarf

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6.1 Discovering the universe

Learning goals

At the end of this section, I will be able to:

1. Understand Aboriginal and Torres Strait Islander Peoples' knowledges of celestial bodies and explanations of the origin of the universe.
2. Explore recent advances in astronomy.
3. Identify the different technologies used to collect astronomical data and the types of data collected.

WORKSHEET Discovering the universe

WIDGET Timeline of the universe

VIDEO The Big Bang

Early astronomers: Aboriginal and Torres Strait Islander Peoples

Aboriginal and Torres Strait Islander Peoples have maintained a deep and complex knowledge of the night sky for tens of thousands of years, including naming celestial objects. Their sophisticated understanding of astronomy has led many scholars to recognise them as some of the earliest astronomers in human history. They have a rich and intricate astronomical knowledge that informs various aspects of their Cultures, including navigation, weather prediction, calendars, cultural identity and storytelling.

Cultural accounts of the origin of the universe vary across Aboriginal and Torres Strait Islander communities, reflecting the diversity of languages, landscapes, and ways of knowing. For example, in many cultures, the Sun is seen as a matriarchal spirit, though she is known by different names depending on the community. These variations reflect the Sun's fundamental role in sustaining life and governing cycles of fertility – an understanding that is central not only to Aboriginal and Torres Strait Islander cultures but to all human societies throughout history.

Many **constellations** are associated with Dreaming stories, and these differ between communities. First Nations Australian astronomy identifies stars and constellations not only by their brightness, but also from patterns originating from the dark clouds. Dreaming stories are part of the **Cultural Lore** of Aboriginal and Torres Strait Islander Peoples. They are part of a living knowledge system and hold a deep cultural and spiritual significance.

constellation a group of stars as seen from Earth that appear to form a familiar shape

Cultural Lore the stories, customs, beliefs and spirituality of Aboriginal people, which is passed down through generations and acts as a guide for everyday life

Did you know? 6.1

Stories based on fact

Aboriginal and Torres Strait Islander Peoples have long included the thylacine in Dreaming stories and Cultural Lore, holding ecological knowledge with rigour that predates European science. The Nuenonne of Bruny Island tell of a thylacine pup gifting its stripes for bravery, while the Arrernte of Mparntwe know Akngwelye as a guardian of Country. These accounts encode detailed observations of species behaviour, habitat, and environmental change, now informing research on extinction, conservation, and environmental history. European science increasingly recognises the depth and scientific validity of Aboriginal Cultural Lore.

Figure 6.1 First Nations Australian rock art depicting a thylacine (*Thylacinus cynocephalus*). Thylacines coexisted with humans alongside megafauna for many thousands of years, but were extinct on the mainland by the time of European colonisation.

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Explore! 6.1

Constellations

The Cultural Lore of many Aboriginal and Torres Strait Islander communities describes the ancestral beings who created the cosmos, including the stars, Moon, Sun and other celestial bodies.

The Seven Sisters, also known as the Pleiades, is a star cluster in the constellation Taurus. The Seven Sisters are culturally important to First Nations Australians. Although star Lore can vary between Indigenous groups, it generally describes seven sisters who are pursued by a man and transformed into stars to escape him. In some versions, the man is an ancestral being who wants to marry the sisters, while in others he is a hero who is trying to catch the sisters for their own good.

Research First Nations Australians' knowledges of celestial bodies and explanations of the origin of the universe.

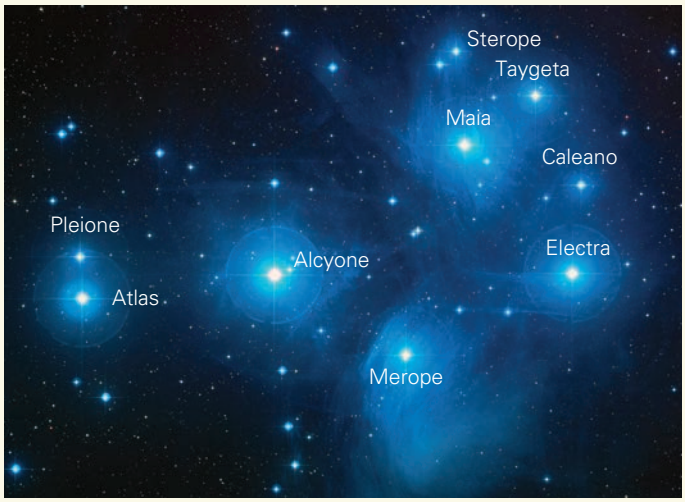

Figure 6.2 The Pleiades is located approximately 400 light years from Earth in the Taurus constellation. In Greek mythology, Atlas and Pleione are the parents of the seven sisters.

Figure 6.3 Painting of the Seven Sisters Dreaming story by First Nations Australian artist Mona Mitakiki

Constellations were important in early human migration and thereby shaped the modern world. Today, astronomers and astrophysicists use advanced technology to make their observations. However, astronomy is a field of science where you do not have to be a professional to take part. An Australian amateur astronomer, Thiam-Guan Tan, discovered a distant planet orbiting a star 40 light years away from Earth from his backyard. The planet is thought to be one of billions of other planets that are 'habitable' – in other words, able to support life.

Other early astronomers

The early astronomers relied on the naked eye to make observations about the positions of celestial objects and how they moved over time.

geocentric a model of the solar system with Earth at the centre

retrograde motion the apparent backward motion of a planet as seen from Earth

Claudius Ptolemy was an astronomer in the second century who suggested that Earth was at the centre of the universe. He proposed a **geocentric** model in which all celestial objects orbited around Earth. It is easy to see why he suggested this model, given that the Sun, stars and Moon all appear to rise in the east, follow a circular pattern as they traverse Earth's sky during the day, and then set in the west.

There was one main problem with Ptolemy's geocentric model. At different points in the year, the planets appear to move backwards in the sky for a few days. This is called **retrograde motion** and could not happen if the planets orbited Earth.

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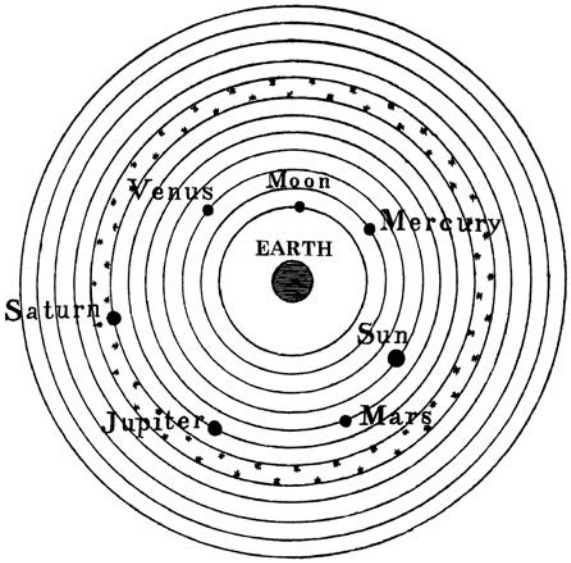

Figure 6.4 The geocentric model proposed that Earth was the centre of the universe, with the planets and stars orbiting around it.

In the early 1500s, Nicolaus Copernicus revived the **heliocentric** model of the solar system, which was initially proposed by the ancient Greek astronomer Aristarchus of Samos almost eighteen centuries earlier. In this model, the retrograde motion of the planets could be explained by the planets revolving around the Sun rather than the Earth.

heliocentric
a model of the solar system with the Sun at the centre

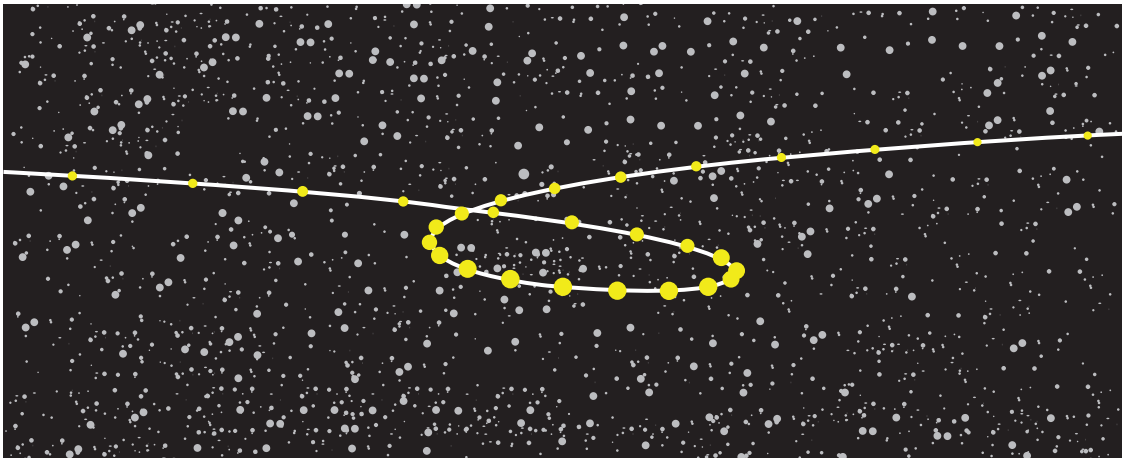

Figure 6.5 Retrograde motion of Mars across the sky as seen from Earth

With the invention of the telescope in the 1600s, Galileo Galilei was able to observe the four largest moons of Jupiter and could confirm that they were orbiting that planet.

Telescopes changed the world of astronomy in a huge way. They allowed us to see the outer planets of the solar system, the moons of other planets, stars which are invisible to the naked eye and galaxies beyond our own Milky Way.

Quick check 6.1

1. **State** the celestial object at the centre of a geocentric model.
2. **State** the celestial object at the centre of a heliocentric model.
3. **Describe** how the circular path of the Sun and stars across our sky each day can be explained.
4. **Recall** those who are known as the 'world's first astronomers'.

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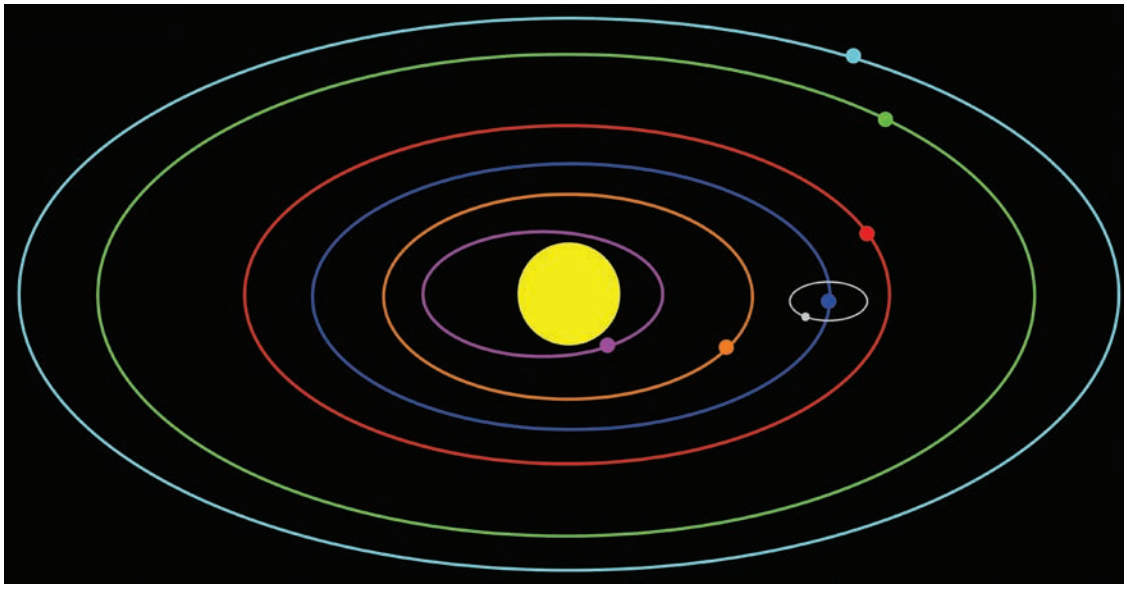

Figure 6.6 The heliocentric model proposes that planets revolve around the Sun, rather than around Earth.

Modern-day astronomy

Modern-day astronomers use a variety of technologies to collect astronomical data as shown in Table 6.1.

Technology	Description
Telescopes	Used to observe radiation across the electromagnetic spectrum. Optical telescopes and radio telescopes are the most commonly used.
Spectroscope	Measures the amount and distribution of light at different wavelengths. It provides information about the chemical composition and temperature of celestial objects.
Photometer	Measures the brightness of celestial objects to study their physical properties, such as size and temperature, as well as their distance from Earth.

Figure 6.7 The Parkes radio telescope in New South Wales was used to receive live television images of the Apollo 11 Moon landing in 1969.

Table 6.1 Technologies used in astronomy

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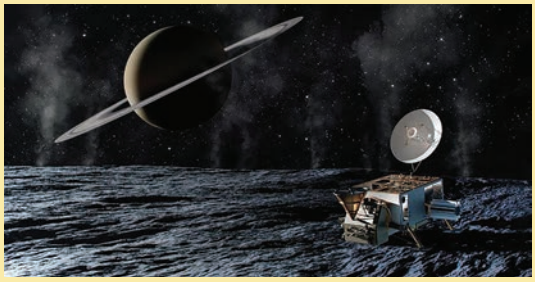
Technology	Description
Interferometer	Through a technique called **interferometry**, it creates high-resolution images by using multiple telescopes to work together as a single, larger telescope to observe the interference of light or radio waves. **Figure 6.8** The Northern Extended Millimeter Array (NOEMA) is an interferometer located in the French Alps. During observations, the multiple antennas work as a single telescope.
Space-based observatories	Allow astronomers to observe celestial objects without the interference of Earth's atmosphere. **Figure 6.9** The Hubble Space Telescope is a space-based observatory that can observe the light from distant galaxies without the dimming effects of Earth's atmosphere.
Space probes	Designed to explore and collect data on atmospheric conditions and surface features of other planets, moons and celestial bodies.  **Figure 6.10** Enceladus Orbilander is a proposed NASA mission aiming to explore Saturn's moon Enceladus. The mission includes a space probe equipped with an orbiter to study the moon's plumes and surface and a lander to investigate its surface materials for signs of life. Set for launch in the late 2030s, it would provide detailed data on Enceladus's potential habitability and its subsurface ocean.

interferometry a technique that uses the interference of waves to measure distances

Table 6.1 *(continued)*

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Table 6.2 shows the data collected by these astronomical technologies.

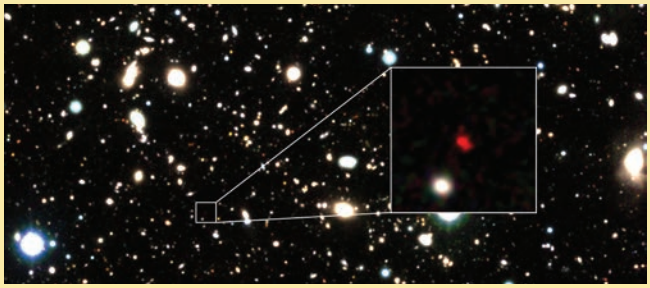
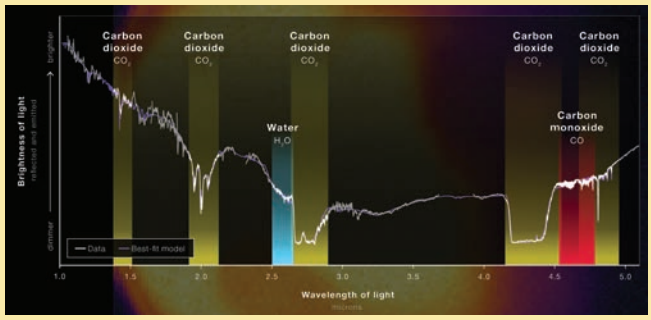
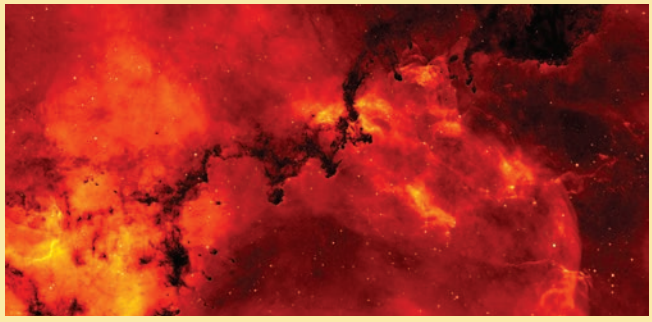
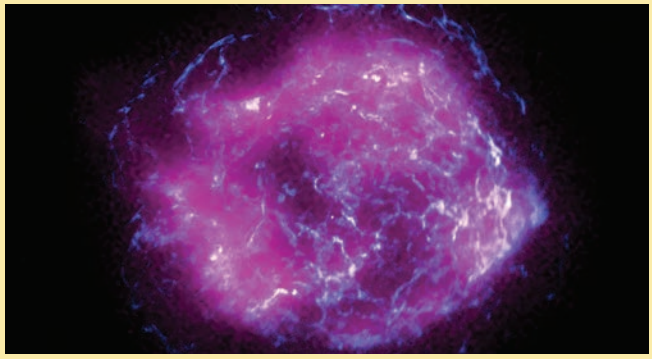
Data	Description
Imaging data	Provides information about the appearance and position of celestial objects.  **Figure 6.11** A three-colour image of HD1 galaxy, which is the red spot in the centre of the zoom box. In April 2022, HD1 was the most distant galaxy ever identified (at a distance of 13.5 billion light years). The image was created using data from four telescopes around the world.
Spectral data	Provides information about the chemical composition and physical properties of celestial objects, such as temperature and density.  **Figure 6.12** This spectrum of Mars combines data measured by the James Webb Space Telescope NIRSpec instrument. NIRSpec stands for near-infrared spectrograph. Spectra like this are created when light is split apart, producing the signatures of water, carbon dioxide and carbon monoxide in Mars's atmosphere.
Photometric data	Provides information about the brightness of celestial objects.  **Figure 6.13** A view of the Rosette Nebula obtained from the Isaac Newton Telescope (INT) Photometric H-Alpha Survey (IPHAS). The red colour comes from hydrogen.
Polarimetric data	Provides information about the polarisation of light from celestial objects, which can be used to study magnetic fields and the properties of dust and gas.  **Figure 6.14** In 2022, astronomers measured and mapped polarised X-rays from the remains of an exploded star called Cassiopeia A using NASA's Imaging X-ray Polarimetry Explorer (IXPE).

Table 6.2 Types of astronomical data

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Data	Description
Astrometric data	Provides information about the position and motion of celestial objects, to determine their distances, motions and orbits.
Surface composition and atmospheric conditions	Provides information about surface composition and atmospheric conditions to understand the geology, climate and potential habitability of astronomical bodies.
Habitability	Provides information about factors such as atmospheric composition, surface temperature, pressure, water presence and environmental stability to determine if conditions can support life.

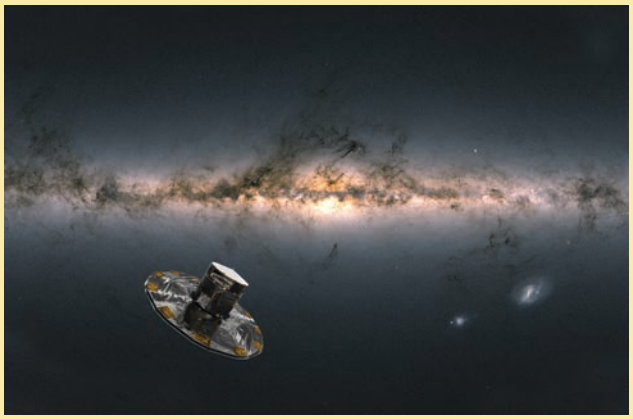

Figure 6.15 Gaia was a space observatory of the European Space Agency (ESA) that was designed to measure the positions, distances and motions of stars.

Figure 6.16 The Mars *Perseverance* rover explores the planet's surface to analyse its geology, search for signs of past water and assess the potential for past or present life.

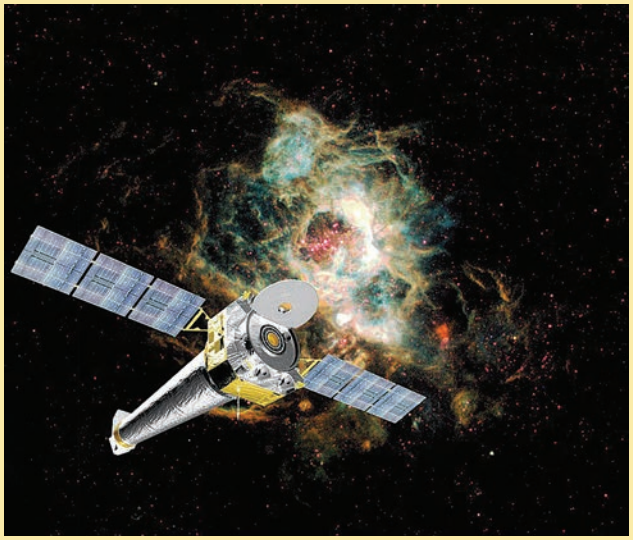

Figure 6.17 X-ray observations from NASA's Chandra and ESA's XMM-Newton are helping astronomers assess exoplanet habitability by evaluating radiation levels, guiding future telescopes in their search for Earth-like planets.

Table 6.2 *(continued)*

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Telescopes

Modern telescopes have become larger and larger to allow us to see further into space. In 1995, the Hubble Space Telescope was pointed towards a region of space previously thought to be empty. The photo produced after two days showed multitudes of galaxies that had never been observed before. It further demonstrated the enormous size of the universe.

To minimise the effects of light pollution and the distorting effects of the atmosphere completely, the Hubble Space Telescope was launched into Earth's orbit and is controlled remotely from the ground. It has been instrumental in developing our understanding of the universe and the Big Bang.

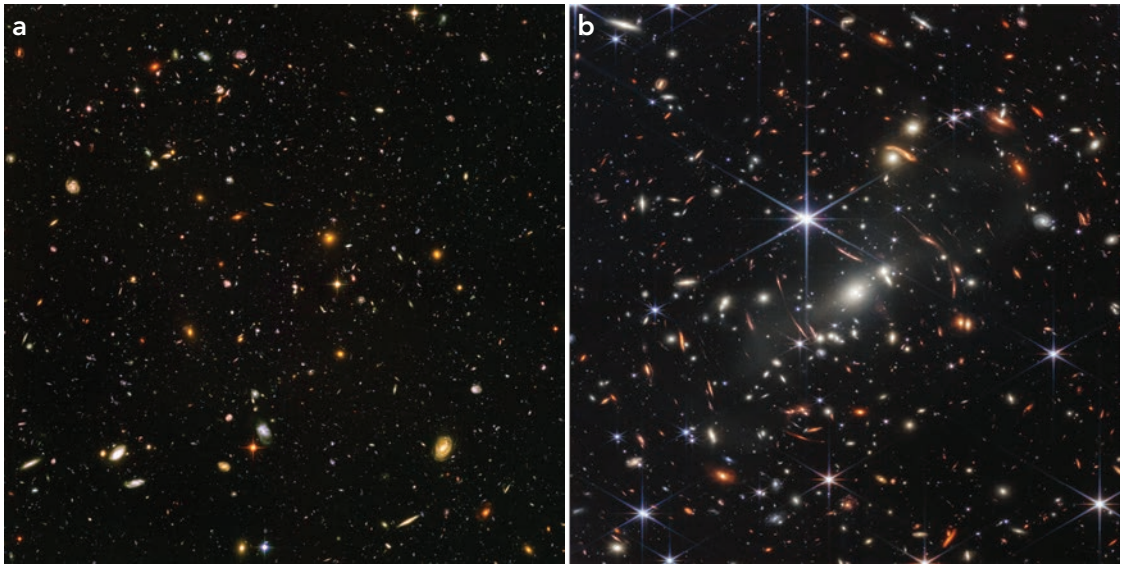

Figure 6.18 (a) A portion of the Hubble Ultra Deep Field image, taken over a period of months from 2003 to 2004. More detailed than the original Deep Field image from 1995, the full image covers a tiny portion of the sky and yet shows approximately 10 000 galaxies, many of which contain billions of stars. **(b)** The new James Webb Space Telescope captured much greater detail again in 2022.

optical telescope a device that collects and focuses light from the visible spectrum to form an image

radio telescope a device that receives radio waves emitted by stars and other celestial objects

The first telescopes were **optical telescopes**, which use lenses to collect visible light and focus it for the eye to see. The larger the diameter of the lens, the more light that can be collected and the further you can see. But, as telescopes got larger, the size of the glass lenses required reached the point where they became too heavy. Sir Isaac Newton first used polished mirrors instead of lenses to collect and focus light in 1668. The Very Large Telescope (VLT) array in Chile has mirrors that are 8.2 metres in diameter, and the Extremely Large Telescope (ELT) under construction in Chile will have a mirror that is 39.3 metres in diameter upon its completion in 2026. Optical telescopes are built in regions of low rainfall to avoid clouds and must be positioned far away from light pollution and at a high altitude to minimise the effects of the atmosphere. The best optical telescopes are located on high mountains in Chile and Hawaii.

VIDEO
The square kilometre array

Figure 6.19 The Square Kilometre Array Pathfinder is made up of 36 identical 12-metre dishes.

Radio telescopes gather information in the form of radio waves. Radio telescopes follow the same principle as optical telescopes in that they collect signals and reflect them inwards to focus them, but the reflective surfaces do not need to be polished mirrors. This means that radio telescopes can be made much larger than optical telescopes. Multiple radio telescopes can also be linked together to look even further into space.

The Australian Square Kilometre Array Pathfinder (ASKAP) in Western Australia is a precursor radio telescope that was built

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to test the technology that will be used in the construction of the full Square Kilometre Array (SKA) Observatory in Australia and South Africa. Composed of 36 dishes and completed in 2012, ASKAP's purpose was to demonstrate the feasibility of the SKA Observatory project.

The SKA radio telescope is expected to be completed in Western Australia in 2028. It will be made up of thousands of dishes whose total collection area will be bigger than one square kilometre (or one million square metres). An artist's impression of the SKA Observatory is shown in Figure 6.20.

Figure 6.20 The Square Kilometre Array Observatory has the potential to look further into space than has ever been possible before.

Did you know? 6.2

Australia's role in space exploration

Australia's space industry is rapidly expanding and is now valued at around $5 billion annually. One of Australia's advantages is its proximity to the equator, which allows satellites to be launched into geosynchronous orbits. This helps reduce the energy required for launches, making space missions more efficient and cost-effective. Australia's southern latitudes also offer access to polar and Sun-synchronous orbits, which are essential for Earth observation and environmental monitoring. Australia also has low levels of noise and light interference that contributes to high-quality data collection and reliable space operations.

The Event Horizon Telescope (EHT) is an international collaboration of radio observatories. It captures images of black holes using very long-baseline interferometry (VLBI) techniques. This allows the participating radio telescopes located around the world to work together as if they were a single telescope. This collective power allows the EHT to achieve a higher angular resolution, making it possible to observe black holes and their properties. Earth's atmosphere only allows light and radio waves through; it blocks the other parts of the electromagnetic spectrum. The ability to place telescopes in space lets astronomers explore the universe by imaging other wavelengths, such as infrared, ultraviolet and gamma rays.

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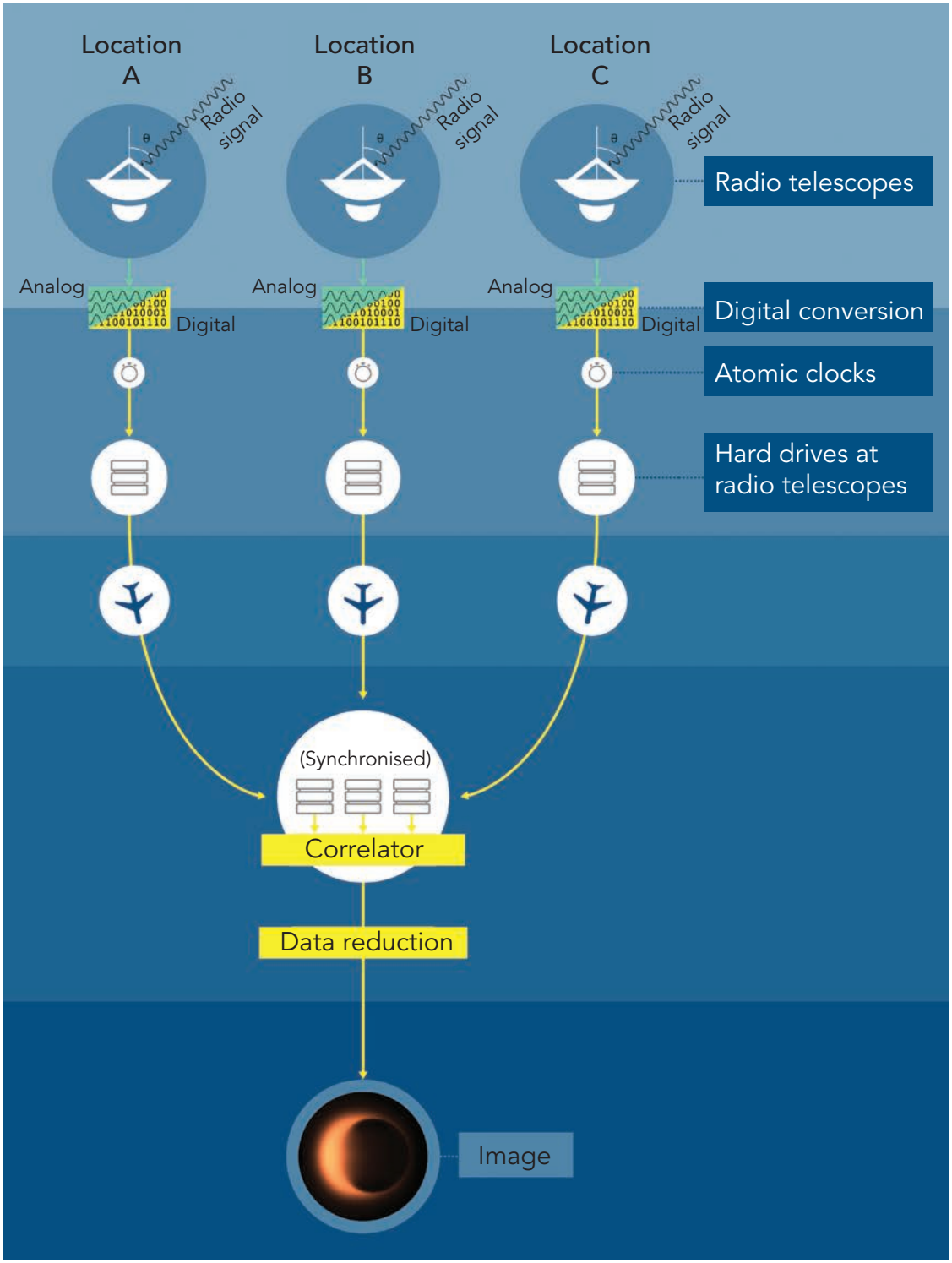

Figure 6.21 VLBI allows multiple antennas to collect signals, which are then converted to digital signals and stored in hard drives. These are then processed at a central location to create an astronomical image.

Quick check 6.2

1. **Name** the two main types of telescopes and recall which part of the electromagnetic spectrum they detect.
2. **Recall** where the best telescopes are located.
3. **Describe** why interferometry is so useful.

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Did you know? 6.3

The James Webb Space Telescope

The James Webb Space Telescope is the largest optical telescope sent into space. It can gather light that has been travelling for 13.5 billion years, almost since the beginning of the universe. It is essentially a time machine, allowing us to observe the first galaxies to form after the Big Bang and how they evolved. As it detects infrared light using a Near-Infrared Camera (NIRCam), it can also see through dust clouds and view objects too old, distant or faint for the Hubble Space Telescope.

Figure 6.22 The James Webb Space Telescope has revealed details about the Tarantula Nebula. Young stars can be seen in pale blue at the centre of the image, while stars that are still developing are shown in red. NIRCam can detect these dust-enshrouded stars due to its resolution at near-infrared wavelengths.

Explore! 6.2

Space junk and satellites

SpaceX's Starlink project, designed to provide global internet coverage through a constellation of satellites, has raised significant concerns about the growing issue of space debris. With plans to launch up to 42 000 satellites, Starlink is contributing to the increasing density of objects in low Earth orbit. Each satellite has a limited operational lifespan, typically around five years, requiring frequent replacements. As these satellites reach the end of their service, they can create debris when they burn up upon re-entry or collide with other objects, adding to the clutter in space.

The accumulation of space junk poses risks to both operational satellites and future space missions. Collisions with debris can damage or destroy spacecraft, creating a hazardous environment for all space activities. Experts are calling for improved regulatory measures and strategies to manage and mitigate space debris, ensuring the future safety of space exploration and satellite operations.

continued ...

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As a class, discuss the following questions.

1. How can we balance the benefits of global internet coverage with the environmental impact of increasing space debris?
2. Should there be international agreements or regulations to limit the number of satellites and manage their end-of-life disposal?

Figure 6.23 Starlink satellites photographed over New Mexico

Go online to access the interactive section review and more!

Section 6.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.1 questions

Remembering

1. **Recall** the reason that most observatories are located in remote areas and at high altitudes.
2. **Name** the data collection method where two or more telescopes are used together.

Understanding

3. **Explain** the advantages and disadvantages of having a telescope in space.

Applying

4. **Draw** a diagram to show the purpose of the large dish on the Parkes radio telescope.

Analysing

5. **Contrast** the geocentric and heliocentric models and explain why the motion of the planets as observed on Earth supports the heliocentric model.

Evaluating

6. **Discuss** the improvements in technology since the time of early astronomers that have allowed us to look further and further into space.

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6.2 Stars

Learning goal

At the end of this section, I will be able to:

1. Describe how stars' light spectra and brightness are used to identify compositional elements of stars, their movements and their distances from Earth.

WORKSHEET
Stars

VIDEO
Star life cycle

With the exception of hydrogen, helium and a small amount of lithium produced during the Big Bang, everything that comprises us and Earth was formed within stars, either through ongoing fusion processes or during supernova explosions.

Nuclear fusion

Many people will describe the Sun and other stars as big balls of burning gas. That is a rather oversimplified explanation of how they produce their energy. In reality, their energy comes from a process called **nuclear fusion**.

Nuclear fusion occurs when two atoms combine (or fuse) to create a new element. Because it is so hot inside the cores of stars, hydrogen nuclei have enough energy to overcome the electrostatic repulsion between their protons. They fuse together to form helium, and an enormous amount of energy is released in the process.

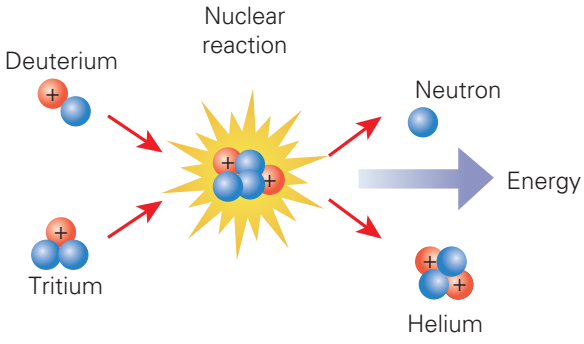

Figure 6.24 One step in the fusion of hydrogen happens when the isotopes deuterium (one proton and one neutron) and tritium (one proton and two neutrons) fuse together. A neutron is released and a helium nucleus is formed (two protons and two neutrons).

nuclear fusion the process of joining two nuclei to produce energy

spectral class a group into which stars are classified based on their spectra

Star colour and temperature

When you look at stars in the night sky, you will notice that they vary in colour. The colour of a star is related to its temperature: blue stars are the hottest and red stars are the coolest. Stars are given a **spectral class** letter based on their temperature and colour (Table 6.3). They were originally classified alphabetically starting at A, but some letters were skipped and others were reordered as more was discovered about star surface temperatures. Our Sun is a relatively small yellow star with a surface temperature of around 6000 kelvin (K), so it is classified as a G-type star.

Colour	Star temperature (K)	Spectral class
Blue	>25 000	O
Blue-white	10 000 to 25 000	B
White	7500 to 10 000	A
Yellow-white	6000 to 7500	F
Yellow	5000 to 6000	G
Orange	3500 to 5000	K
Red	<3500	M

Table 6.3 Temperatures and spectral classes of stars of different colours

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B–V colour index

Most stars look white, but a few, such as Betelgeuse, seem to have a very slight reddish tinge. So how do we know what the colours of stars are? Astronomers measure the brightness of stars through different coloured filters. They subtract the amount of light that comes through a green filter (called the visual filter) from the amount of light that comes through a blue filter. This is called the **B–V colour index**. The lower (or more negative) the number, the bluer the star, and the higher (or more positive) the number, the redder the star. Rigel, a large blue star, has a B–V colour index of –0.03, for example. Betelgeuse, a large red star, has a B–V colour index of 1.85.

B–V colour index the difference in brightness measured through blue and green filters, indicating the colour of a star

continuous spectrum all wavelengths within a specific range

absorption spectrum a spectrum showing dark lines representing specific wavelengths that have been absorbed by a substance

emission spectrum a spectrum showing bright lines representing specific wavelengths specific that have been emitted by a substance

luminosity the intrinsic brightness of a celestial object

Quick check 6.3

1. **Recall** the name of the process that occurs inside stars.
2. **Recall** what the colour of a star tells us.
3. **State** the colour of a star with a temperature of 5500 K.

Explore! 6.3

Spectral classes

Aldebaran is the brightest star in the Taurus constellation. It is classified as an orange K-type star and has a surface temperature of around 4000 K. Research examples of stars that belong to each spectral class (O, B, A, F, G, K and M).

Light from stars

All stars emit a full range of wavelengths from the visible spectrum (colours). This means you would observe a complete rainbow if you were to split the star's light into different colours using a prism. The peak of a star's spectrum depends on its temperature. This peak wavelength is the one that the star emits most of and is the colour that we observe the star to be. You will notice that there are no green stars listed in the spectral class system. There actually are stars whose spectrum peaks are in the green part of the spectrum, but their total combination of colours emitted appears white to our eyes.

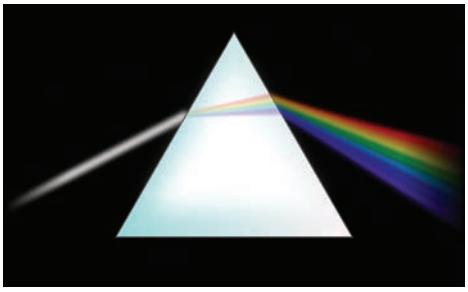

Figure 6.25 White light consists of the full range of wavelengths (colours) from the visible spectrum.

A **continuous spectrum** contains all the wavelengths and colours possible from the visible spectrum. When light passes through gas (like through an atmosphere), some of the wavelengths (colours) of light are absorbed, and black lines will appear in the spectrum. This is called an **absorption spectrum**. We can compare that to light produced by the gas itself, which absorbs and emits light of a single wavelength. This produces an **emission spectrum**. Figure 6.26 shows the differences between these spectra.

Luminosity

In general, stars that are located far away are expected to appear less bright than those that are closer. However, if you were able to observe all stars from the same distance, they would not all appear equally bright. The brightness of a star depends on its **luminosity**, and stars that produce more light are considered to be more luminous. Luminosity is measured on a scale on which our Sun has a luminosity of 1. A star with a luminosity of 100 would be 100 times brighter than the Sun when observed from the same distance.

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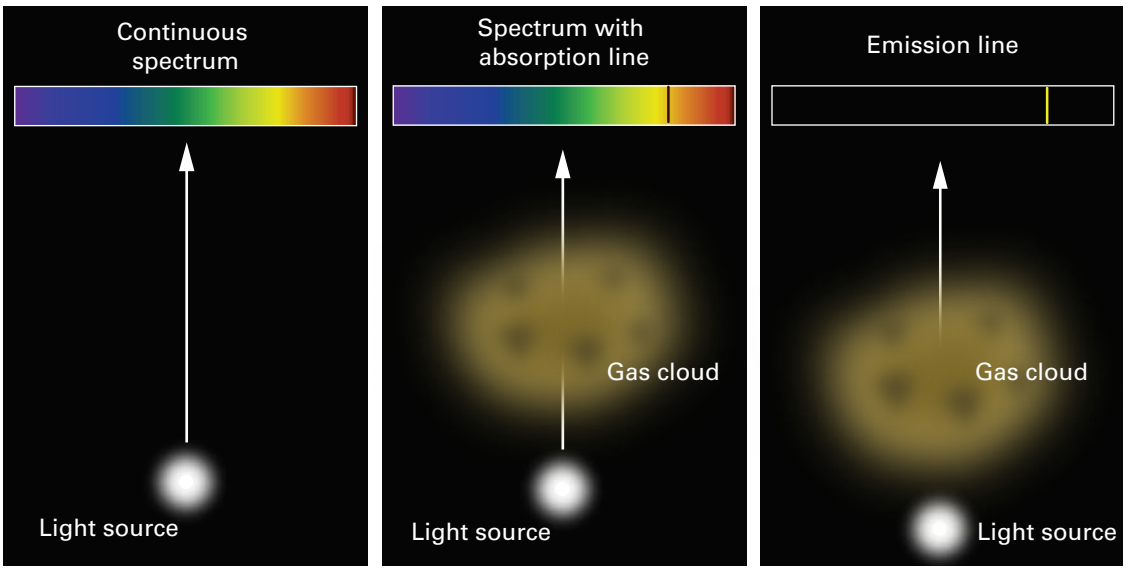

Figure 6.26 A demonstration of how the three types of spectra are produced

Practical 6.1

Flame tests and observing emission spectra

Be careful
Wear appropriate personal protective equipment, including safety glasses. Wash your hands after the practical.

Aim

To investigate how emission spectra can be used to determine the metal in unknown substances.

Materials

- 1 mol L^{-1} solutions of copper(II) chloride, potassium chloride, sodium chloride, lithium chloride and strontium chloride
- unknown solutions labelled A, B and C (A, B and C should each contain one of the known solutions above)
- wooden splints
- Bunsen burner
- bench mat
- matches
- emission spectrometer

Method

Part 1: Prepare the results table

Copy the results table into your science book.

Part 2: Test the known solutions

1. Set up the Bunsen burner with a bench mat and attach the Bunsen burner to the gas.
2. Turn on the Bunsen burner and adjust it to produce a blue flame.
3. Dip the wooden splint into the first known solution and place it in the flame.
4. Observe the colour and record it in the results table.
5. Dip the same splint into the same solution and have your partner observe the flame through the spectroscope.
6. Draw lines on the results table to match the spectral lines shown through the spectroscope. Take note of the very faint dark lines, the most notable being at wavelengths of 4.9 and 5.2 (in hundreds of nanometres).
7. Repeat steps 4–6 with the other known solutions.

Part 3: Test the unknown solutions

Repeat steps 4–6 and record the colour and emission spectra for the unknown solutions.

continued …

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Results

Determine the metal present in the unknown solutions (labelled A, B and C) and record in the table by drawing lines that match the colours you see. The first row has been completed as an example.

Solution	Flame test	Spectroscope						
	Colour in flame	Colours (wavelength in hundreds of nanometres)						
		4	4.5	5	5.5	6	6.5	7
Known solution								
Copper(II) chloride	Blue or bluish-green							
Lithium chloride								
Strontium chloride								
Sodium chloride								
Potassium chloride								
Unknown solution								
A								
B								
C								

Discussion

1. Determine the identity of the three unknown solutions. Justify your statements with data.
2. At which wavelengths would you observe dark lines in the Sun's spectrum? Research which elements are found in the Sun's atmosphere that coincide with spectral lines at those wavelengths.
3. Suggest why spectra are referred to as 'fingerprints' of the stars. Explain how the data supports the statement.

Star life cycle

Stars do not have a limitless fuel source. Most stars produce light by converting hydrogen to helium, but all stars will eventually run out of nuclear fuel and will evolve. The changes that stars go through in their lifetime is predictable and depends on their size.

Birth of stars

nebula (plural: nebulae) a cloud of gas and dust in space

main sequence the phase during which stars convert hydrogen into helium in their cores

Stars form inside clouds of dust and gas called **nebulae**. The dust and gas collapse under their own gravity and form a protostar. Over millions of years, a protostar stabilises and begins nuclear fusion.

Main sequence stars

Stars spend most of their life in the **main sequence**. This is the phase in which they convert hydrogen into helium via nuclear fusion. Roughly 90% of known stars are in the main sequence. Our Sun is 4.6 billion years old and will spend another five billion years in the main sequence before it moves to its next stage.

Figure 6.27 In 2023, the James Webb Space Telescope released an image showing a young cluster of stars known as NGC 346. Located more than 200 000 light years from Earth, scientists believe it resembles the conditions of the early universe when stars were being rapidly formed.

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Red giants

As an average-sized star's hydrogen is converted into helium, the helium builds up in the core of the star. The region where hydrogen is still undergoing fusion becomes a shell around the core, and the star will gradually increase in size to become a **red giant**. For our Sun, this size increase will begin in roughly five billion years, and the red giant will envelop the first four planets in our solar system (including Earth). Nuclear fusion in the core of a red giant will then begin to fuse helium into heavier elements.

When a red giant runs out of fuel, its outer layers drift off in a **planetary nebula** (a cloud of gas and dust) and its core collapses into a **white dwarf**. The white dwarf will slowly cool over time and eventually be no longer visible. A star at this stage is given the name black dwarf, but it is only theoretical because a black dwarf is expected to take longer to form than the current age of the universe!

red giant
a very large, bright, cool star that has run out of hydrogen in its core

planetary nebula
a type of nebula that forms as a result of a red giant throwing off its outer layers

white dwarf
a small, dense, dim star that has lost its outer layers and is at the end of its lifetime

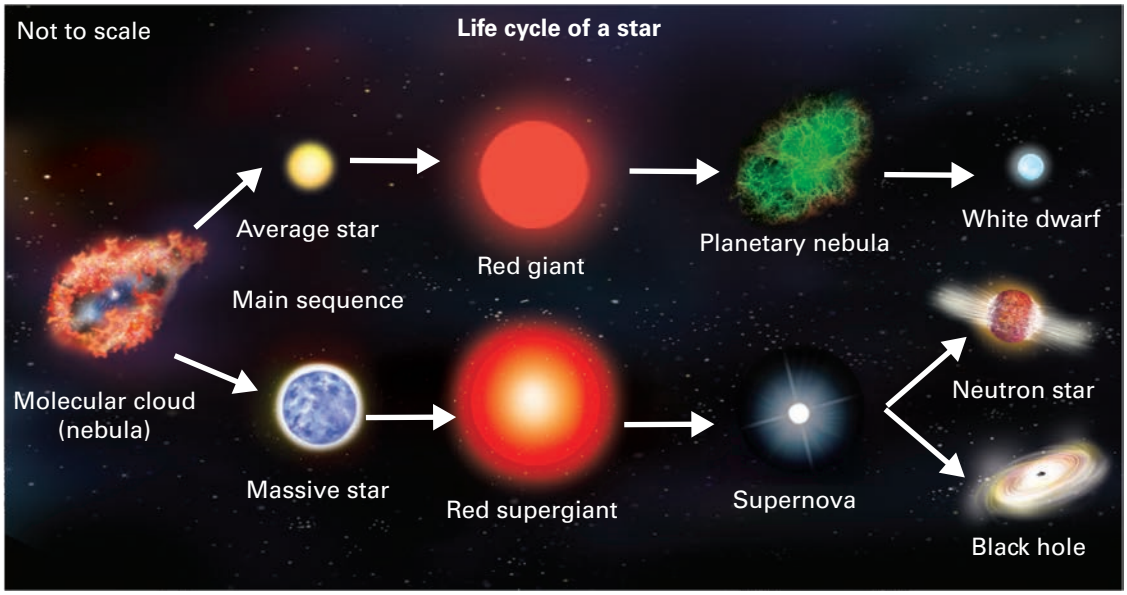

Figure 6.28 How stars change over time depends on their size. Although it doesn't look like it, star formation is cyclical in nature. The material blown off during the planetary nebula phase or a supernova phase eventually ends up in a molecular cloud, forming a new protostar.

Supergiants

Stars that are more than 10 times the mass of our Sun take a different path. Massive stars have a much shorter lifespan than smaller stars like our Sun. They may be anywhere up to 50 times as massive as our Sun but can be more than a million times brighter. This means that they are hotter and consume fuel much faster than smaller stars. Massive O-type stars may only live for a few million years because they consume their fuel so quickly, whereas the smaller K-type and M-type stars live for many billions of years.

Supernovas

When a supergiant runs out of fuel, it collapses under its own gravity and produces an enormous explosion called a **supernova**. All the elements heavier than iron, such as uranium and gold, are theorised to have been created during these spectacular explosions.

Figure 6.29 A mosaic image of the Crab Nebula taken by the Hubble Space Telescope. This expanding remnant of a star's supernova explosion is six light years wide.

supernova
the explosion of a massive star

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neutron star
a tiny, hot, dense star formed when a star explodes as a supernova; made only of neutrons

black hole
the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing can escape, not even light

galaxy
a gravitationally bound system containing billions of stars and planets

Usually, if a star is less than 40 times the mass of our Sun, it collapses into a **neutron star**, while a star that has a mass greater than 40 times the mass of our Sun will become a **black hole**.

Black holes

If the mass of a star prior to the supernova explosion is great enough, the amount of gravity can be so enormous that the core of the remaining star collapses into a tiny amount of space. This is called a black hole. We cannot see black holes because they do not emit light, but we can observe them indirectly by the effects that they have on objects around them. Some black holes have a diameter of only a few kilometres but the mass of 10 000 Suns! There is a supermassive black hole at the centre of the Milky Way **Galaxy**, and astronomers predict that most spiral galaxies have a black hole at their centre.

Quick check 6.4

1. **Recall** which factor determines the path that a star takes through its lifetime.
2. **List** the order of phases that a Sun-like star will go through in its lifetime.

Explore! 6.4

Spaghettification and black holes

Black holes have captured the imagination of astronomy enthusiasts, science fiction writers and astrophysicists alike since their existence was hypothesised in the early 1900s. There are many theories surrounding black holes and how light and matter can interact with them.

1. Research the ideas behind spaghettification and black holes, and summarise the main concepts in a few paragraphs.
2. Propose what it might look like to watch something travel into a black hole.

Did you know? 6.4

Imaging black holes

The first direct image of a black hole was taken by the Event Horizon Telescope (EHT) in 2019. The black hole is in the centre of galaxy M87, and a network of eight radio observatories on four continents collected data for 10 days to capture the image. Scientist Dr Katie Bouman developed an algorithm called CHIRP to process the enormous amount of data gathered by the EHT project.

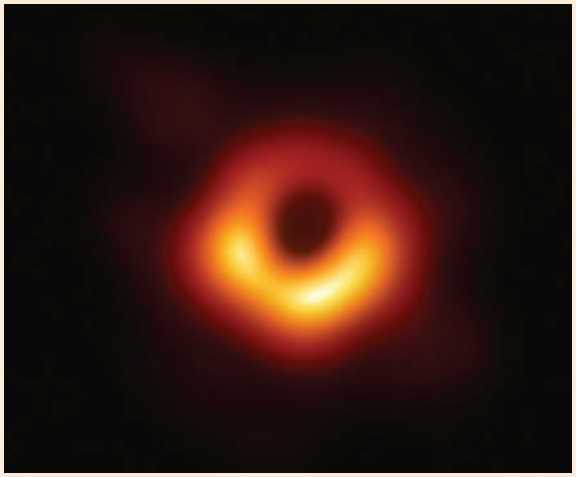

Figure 6.30 The black hole at the centre of galaxy Messier 87

The image is not a photograph. Instead, the algorithm created it using the data. The black hole itself can't be seen because light can't escape from it. The golden ring in the image is orbiting material just outside the event horizon, inside of which nothing can escape the black hole's massive gravitational pull.

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Did you know? 6.5

LIGO

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is designed to directly detect gravitational waves. Gravitational waves are ripples in space-time (the 'fabric' of the universe) that are produced by extreme events, such as the collision of two black holes. LIGO uses laser interferometry to measure tiny distortions in space caused by passing gravitational waves.

The observatory consists of two facilities, located in Hanford, Washington, and Livingston, Louisiana, USA, which work in unison to detect gravitational waves from cosmic sources. LIGO's detection of gravitational waves in 2015 marked the beginning of the new field of gravitational-wave astronomy and created new opportunities for observing the universe.

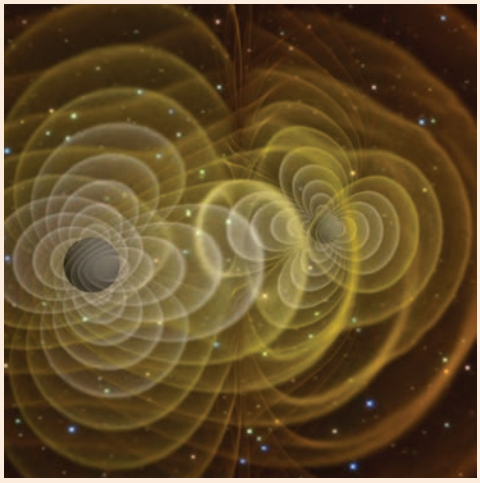

Figure 6.31 This picture of a three-dimensional simulation of merging black holes was created by a supercomputer at the NASA Ames Research Center. The development of fast computers has allowed astrophysicists to explore the universe in an entirely new way, through the detection of gravitational waves.

Hertzsprung–Russell diagrams

A Hertzsprung–Russell or **H–R diagram** is a plot of star luminosity (relative to the Sun at 1) against star temperature. In Figure 6.32 you can see a diagonal band of coloured dots that represent stars in the main sequence. Red giants, supergiants and white dwarfs have their own sections on the H–R diagram.

H–R diagram (Hertzsprung–Russell diagram) a graph where the star luminosity is plotted against temperature

Remember, the luminosity scale gives us an idea of how bright a star is compared to the Sun. Stars with a luminosity of 1 are as bright as our Sun.

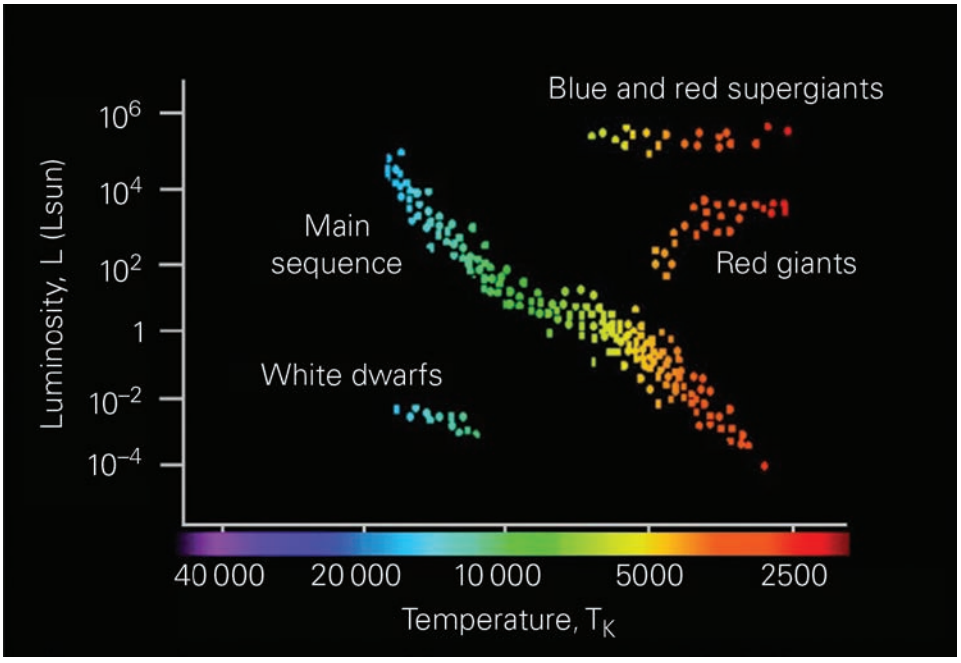

Figure 6.32 A Hertzsprung–Russell diagram plots star brightness (luminosity) against surface temperature.

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Section 6.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.2 questions

Remembering

1. **Recall** the temperature and luminosity of our Sun.

Understanding

2. **Describe** the process by which a star forms.
3. **Explain** the two factors that determine how bright a star appears from Earth.

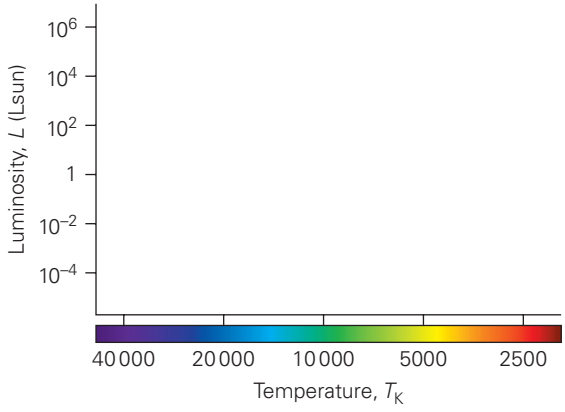
Applying

4. **Summarise** the observable features of stars and how they relate to each other.

Analysing

5. Copy and use the H–R diagram below to plot the following stars on it. **Examine** the graph to answer the following questions.

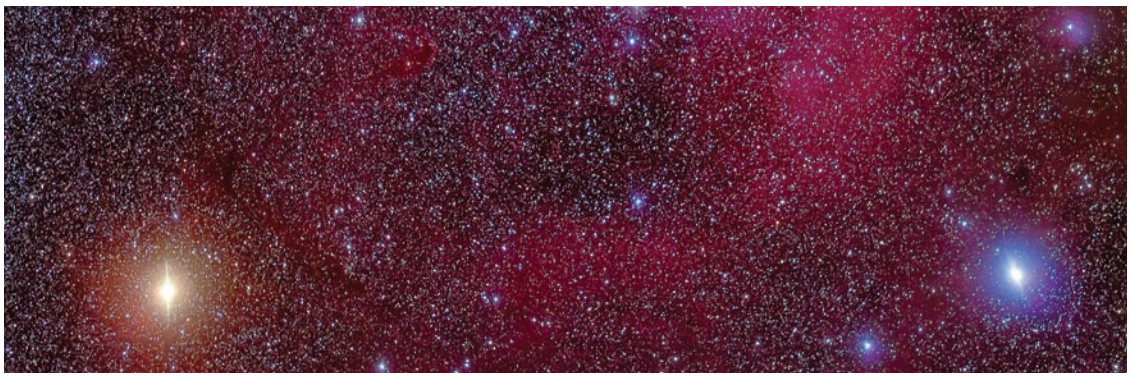
Star	Temperature (K)	Luminosity (Sun = 1)
Sirius	9940	25.4
Canopus	7350	10700
Arcturus	4290	170
Alpha Centauri	5790	1.5
Vega	9602	40
Rigel	11000	120000
Betelgeuse	3500	140000



a) Which of the stars you have plotted is a red supergiant?
b) Which of the stars you have plotted is most like our Sun?
c) What colour is Canopus? How do you know?
d) How many times brighter than the Sun is Sirius?
e) Will Rigel's lifetime be longer or shorter than the Sun's? Explain your answer.

Evaluating

6. **Propose** a reason why nobody has ever seen a black hole. How do we know that they are there?



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6.3 Beyond the Milky Way

Learning goal

At the end of this section, I will be able to:

1. Describe the major components of the universe.

WORKSHEET
Beyond the Milky Way

All the individual stars that you can see in the night sky with the naked eye are within the Milky Way Galaxy. It can be difficult to imagine the immense distances in space unless there is some perspective. Our closest star is the Sun, and it takes 500 seconds (about eight minutes) for light to travel from the Sun to Earth (a distance of 150 000 000 km). The closest star to our solar system is Alpha Centauri. Light takes 4.4 years to travel from Alpha Centauri to Earth. Our solar system is positioned on an outer arm of the Milky Way, and it takes light 106 000 years to travel across the Galaxy. Our closest galaxy is the Andromeda Galaxy, and it takes light 2.5 million years to travel to Earth from Andromeda. There are over two trillion galaxies in the **observable universe** (that is, the part of the universe we can see). In 1936, the astronomer Edwin Hubble classified the Local Group as a group of 12 galaxies, which includes the Milky Way and the Andromeda Galaxy. Since then, as we have learned more, the Local Group has grown to 36 galaxies.

observable universe the spherical region of the universe that can be observed from Earth or space telescopes; it encompasses everything close enough that light has had time to reach Earth

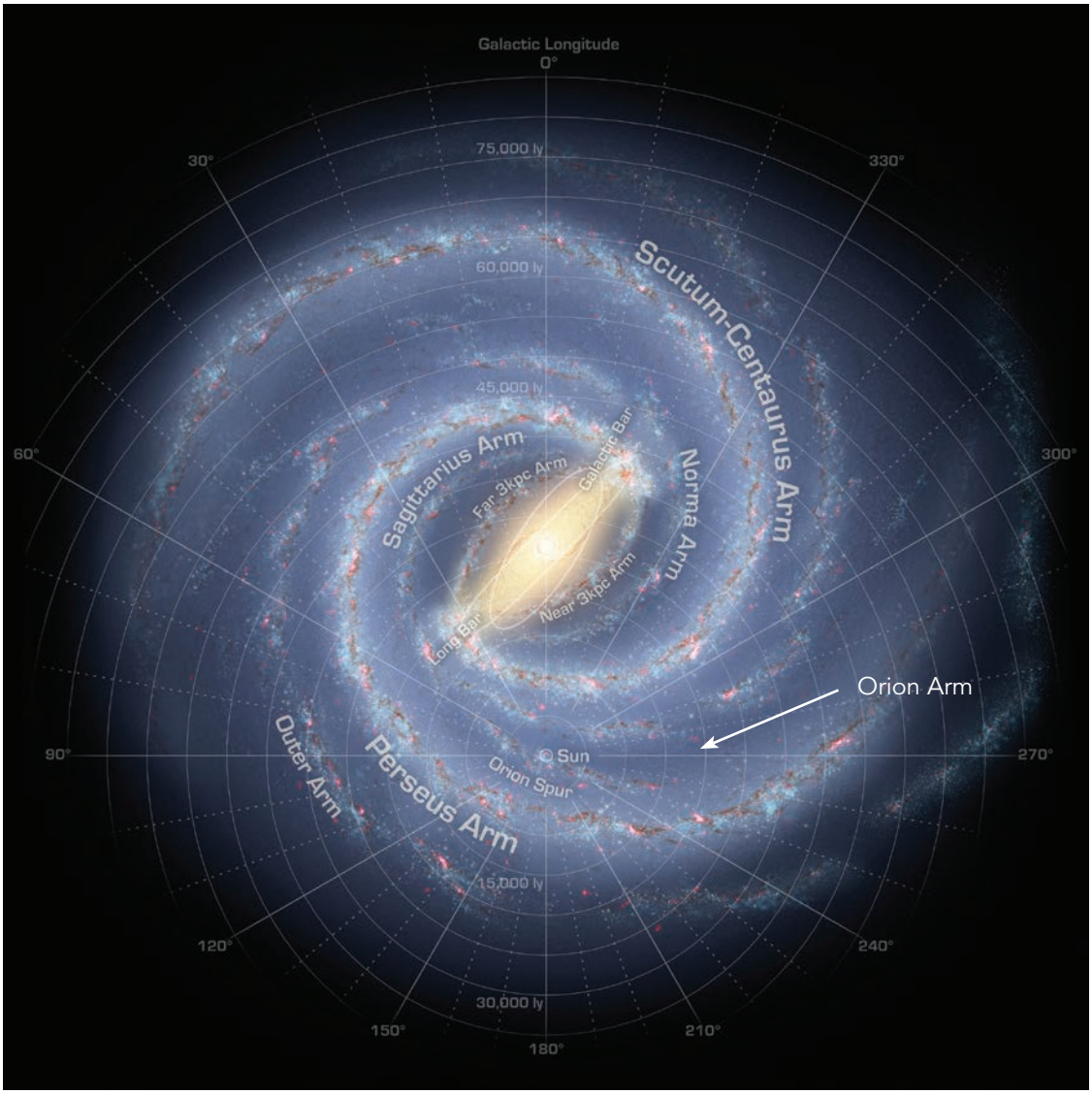

Figure 6.33 Our solar system sits on the Orion arm of the Milky Way.

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Making thinking visible 6.1

See, think, wonder: Eagle Nebula

Figure 6.34 shows star-forming pillars called the Pillars of Creation, which can be found inside the Eagle Nebula. The image is composed of 32 different images from four separate cameras. The missing part at the top right is because one of the four cameras has a magnified view of its portion, so the images from this camera were scaled down to match those from the other three cameras.

The photograph was made with light emitted by different elements in the cloud, which appear as different colours in the composite image: green for hydrogen, red for sulfur and blue for oxygen.

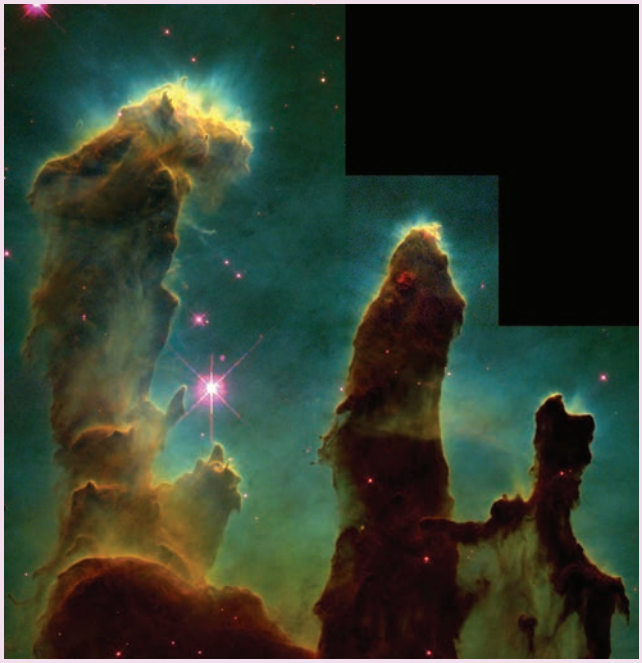

Figure 6.34 Star-forming pillars in the Eagle Nebula, as seen by the Hubble Space Telescope's Wide Field and Planetary Camera 2

1. Can you describe what is visible in the photo?
2. What thoughts come to your mind when you observe it?
3. Are there any questions that arise from your observations?

The *See, think, wonder* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

VIDEO Galaxy classification

Galaxies

Galaxies are classified by their shape according to the Hubble galaxy classification scheme. Galaxies can be classified as elliptical, lenticular, spiral or irregular.

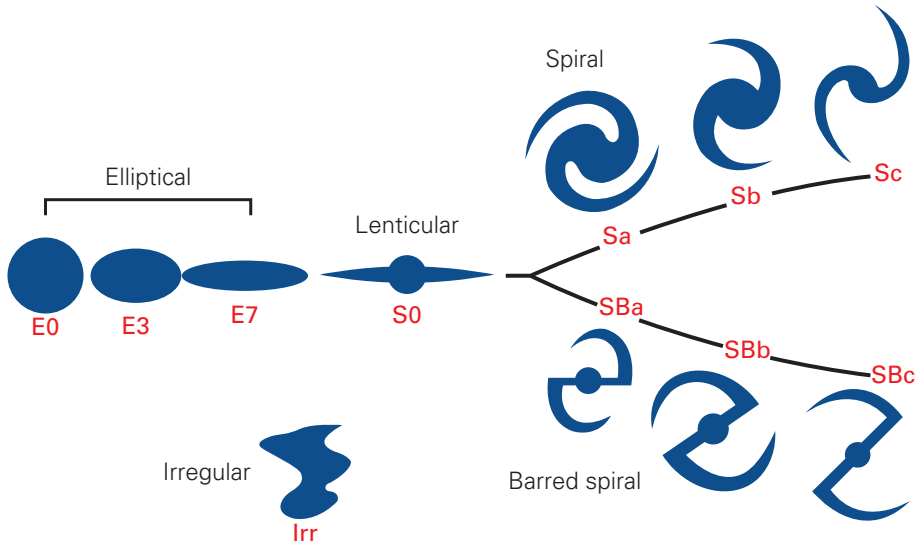

Figure 6.35 Hubble's galaxy classification scheme

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Quick check 6.5

1. **Classify** the following galaxies using Hubble's classification scheme.

Try this 6.1

Classifying galaxies

Astronomers now have so many photos of galaxies that they simply do not have the time to classify them all. A group of astronomers has set up a crowd-sourced astronomy project called Galaxy Zoo that allows anyone to take part in some real science. You can try this too.

Search for Zooniverse Galaxy Zoo on the internet and you can have a go at classifying galaxies for yourself. You will be shown a galaxy and asked a series of questions about what you can see and the shape of the galaxy. Do not be afraid that you will get it wrong – the galaxies are shown about 30 different times to make sure that the responses are consistent.

Astronomical distances and the speed of light

Light travels at a speed of 300 million metres every second, which can be expressed using index notation as 3×10^8 m s^{-1}. A **light year** is a unit of distance equivalent to how far light travels in a year, which is equal to 9.46 trillion kilometres.

light year
the distance that light travels in one year (about 10 trillion km)

Try this 6.2

Cheese and light

Be careful
Handle with care as cheese may be extremely hot.

Use your microwave to calculate the speed of light!

1. Open your microwave and remove the rotating platform.
2. Line a dinner plate with cheese singles and place it in the microwave.
3. Turn on the microwave for about 10 seconds or until small hotspots start to form on the layer of cheese.
4. Take the plate out of the microwave and measure the distance between two of the hotspots. This value will be half of the wavelength of the microwave radiation.
5. Locate the frequency of your microwave in hertz (Hz), which should be listed inside the door.
6. Use the formula $v = f\lambda$, where v is the speed in m s^{-1}, f is the frequency in hertz and λ is the wavelength in metres, to calculate the speed of light (remember to multiply your hotspot measurement by two to get the wavelength). Compare it to the actual value.

Figure 6.36 A microwave wave heating up a slice of cheese

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Parallax

parallax the effect by which the position of an object seems to change when it is observed from different locations

astronomical unit the distance between Earth and the Sun

baseline a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

parsec the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

arcsecond 1/3600th of a degree

One method of measuring distances in space is by using **parallax**. If you hold your index finger in front of you at arm's length and close one eye, then swap eyes and close the other one, your finger will appear to move because you are essentially observing your finger from a different location. The same thing happens when we look at the stars in the night sky from a different position in space. As Earth travels around the Sun, our position in space changes and we see the stars arranged slightly differently. We can measure the angle between the apparent location of a nearby star and a 'fixed' distant star. This is called the parallax angle. Using the distance between Earth and the Sun (the **astronomical unit** or AU) as the **baseline** and some trigonometry, we can work out how far the star is from Earth.

This technique enables us to measure distant stars in **parsecs** (pc): one parsec is equal to 3.26 light years or 30 trillion kilometres. A star that is one parsec away will have a parallax angle of one **arcsecond**, which is one 3600th of a degree (there are 60 arcminutes in one degree and 60 arcseconds in one arcminute).

Using parsecs to measure distance makes it easier to calculate distances with the following formula:

$$\text{Distance to star (in pc)} = \frac{1}{\text{parallax angle (in arcseconds)}}$$

The further away a star is, the less it appears to move due to parallax, and the smaller the parallax angle becomes. This gives a limit to the distance that we can measure using the parallax method, because when stars are too far away, their parallax angle is too small to measure. The limit to which we can use parallax is around 100 parsecs.

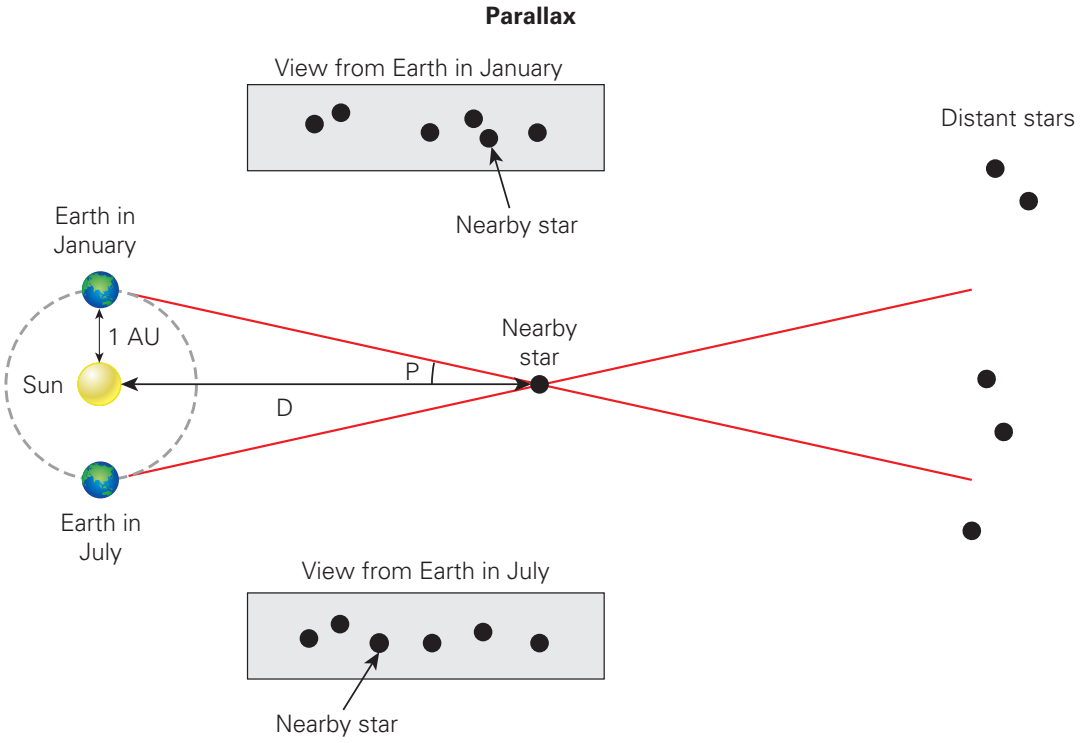

Figure 6.37 Astronomers can work out the distance to nearby stars by comparing their apparent location relative to the background of distant stars (which are unaffected by parallax).

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Quick check 6.6

1. **Recall** whether a a light year measures time or distance.
2. **State** the limit out to which star distance can be measured using the parallax method.
3. **Determine** whether a closer star will have a larger or smaller parallax angle.

Practical 6.2

Parallax

Aim

To investigate the use of parallax angles to reliably calculate distance.

Materials

- an 'object' (something that can be placed in the middle of the school oval and be visible from the perimeter)
- ruler × 2
- large protractor
- trundle wheel

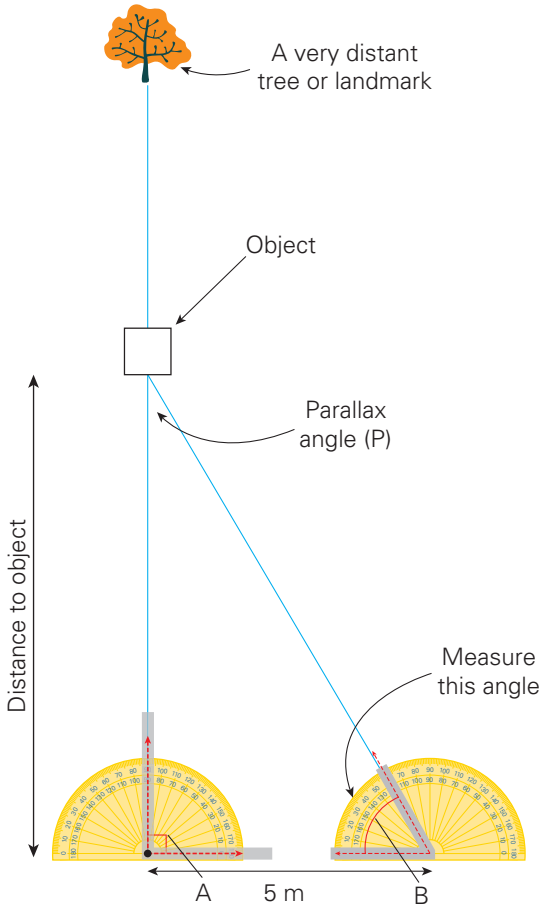
Method

Part 1: Prepare the results table

Copy the results table into your science book. You will be collating your results with the class to analyse the reliability of this method.

Part 2: Set up the distances

1. Your teacher will place an object in the middle of the school oval (the whole class will determine the distance to this one object).
2. Find a location near the perimeter of the oval where the object lines up with a distant landmark – for example, a tree, the edge of a fence, a gate, the edge of a building or a flagpole.
3. At this location, use the two rulers and protractor to make a right angle, angle A, perpendicular to the line going through the object and the landmark, as shown in the diagram.
4. Measure out a 5-metre line along this perpendicular direction (this will be your baseline).
5. At the end of the 5-metre line, use the two rulers and protractor to measure angle B (between the baseline and the ruler directed towards the object). (You may have to lie on your stomach to line up the objects by sight.)



Results

1. Calculate the parallax angle (P) by subtracting the angle (B) from 90°.
2. Use trigonometry $D = \frac{5}{\tan(P)}$ to calculate the distance (D) to the object.
3. Use the trundle wheel to measure the actual distance to the object.
4. Calculate the relative error.
5. Combine data on a class board or spreadsheet.
6. Draw a scatter plot to analyse the relationship between the distance to the object and its parallax angle.

continued ...

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7. Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.

	Baseline distance (m)	Angle B (°)	Angle $P = 90 -$ angle B (°)	Calculated distance to the object (m)	Measured distance to the object (m)	Relative error $\frac{\text{Measured distance} - \text{Calculated distance}}{\text{Measured distance}} \times 100$
Group 1	5					
Group 2	5					
Group 3	5					
Group 4	5					
Group 5	5					
Group 6	5					
Mean	5					

Discussion

1. Describe the relationship between the parallax angle and the calculated distance.
2. Describe the amount of relative error for your own calculations and the mean relative error for the class group.
3. Instrument error is one factor that could affect the precision of the experiment. Were other factors that could affect the validity of the results successfully controlled during the experiment? Justify your reasoning.
4. Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

VIDEO
The Doppler effect

Doppler effect a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

blue shift when a spectrum has shifted towards shorter wavelengths

red shift when a spectrum has shifted towards longer wavelengths

Extension: The Doppler effect

When you hear an ambulance travelling past you, the pitch of the siren changes as it passes. When the ambulance is travelling towards you, the sound wave is a little more squashed than usual, which results in a higher-frequency wave. You hear it as a higher pitch. When the ambulance is travelling away from you, the sound wave is a little more stretched than usual, which results in a lower-frequency wave. You hear it as a lower pitch. This phenomenon is called the **Doppler effect** (see Figure 6.38).

The same phenomenon happens with light waves if an object is travelling fast enough. When the object is travelling towards you, the light it emits is of a higher frequency, which translates to the light appearing more blue. This is called **blue shift**. When the object is travelling away from you, the light it emits is of a lower frequency, which translates to the light appearing more red. This is called **red shift** (see Figure 6.39).

When astronomers look at spectra from distant galaxies, they find that the emission lines are almost always shifted towards the red part of the spectrum. This tells us that most galaxies in the universe are moving away from us and the universe is expanding.

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Travelling large distances

Our Earth is not going to be around forever. It may become uninhabitable because of human activity, it may get enveloped by our Sun expanding into a red giant in five billion years, or it may be destroyed by a giant meteor or nearby supernova. For humanity to get the chance to leave Earth to look for somewhere else to live, we will need to find a way to travel large distances and leave our solar system.

Interstellar travel (travelling outside our solar system) throws up quite a few problems. These problems relate to the vast distances that we would need to travel to find and inhabit a new planet. Light takes just over four years to reach the closest star to our solar system, Alpha Centauri. We cannot travel even remotely near the speed of light with current technology. Even if we develop such technology in the future, travelling close to the speed of light has its own problems: it would require an enormous amount of energy to accelerate a conventional spaceship leaving Earth to 99% of the speed of light, and an equally enormous amount of energy to decelerate at journey's end.

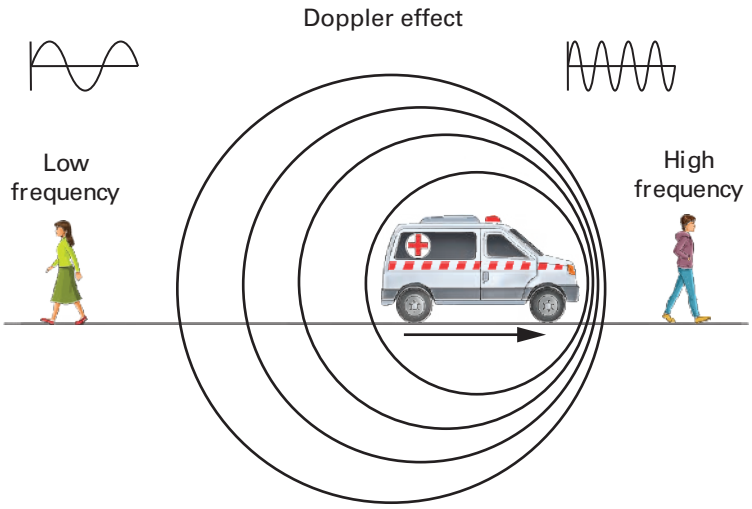

Figure 6.38 Sound waves are squashed together as the ambulance travels into them, so we hear a higher pitch as the ambulance drives towards us. Sound waves are spread out as the ambulance moves away from them, so we hear a lower pitch as the ambulance drives away.

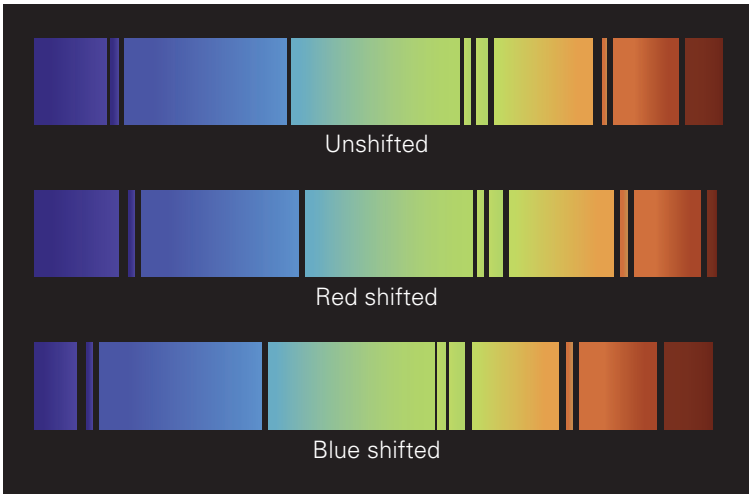

Figure 6.39 The black lines from a galaxy's absorption spectrum are red shifted if the galaxy is moving away from us and blue shifted if it is moving towards us.

Finding **exoplanets**, planets that orbit other stars, is a lot harder than you might imagine. We can easily observe stars because they emit their own light. Planets only reflect light from the star they orbit, so they are many orders of magnitude dimmer than a star. We cannot see the light from most planets outside our solar system because we are just too far away from them, so the only way we can tell that they are there is indirectly, such as when they pass in front of their own star and block out a tiny portion of its light (like a mini eclipse).

exoplanet
a planet outside our solar system, orbiting a star other than our Sun

Goldilocks zone
the habitable zone around a star where the temperature is not too hot and not too cold

Despite this difficulty, astronomers have found over 5000 exoplanets! The problem we then encounter is finding out whether humans could live on these planets. A liveable planet would need to be made of rock (so that we can land on it) and have an atmosphere so we do not die from the radiation in space (but not so thick that the greenhouse effect makes it unbearably hot). The planet would need to be in what is called the **Goldilocks zone**: not too hot and not too cold.

Out of all the exoplanets that have been discovered, only a small number could potentially be habitable. However, astronomers have predicted that there might be more than 10 billion exoplanets orbiting Sun-like stars just in our own galaxy.

Given the immensely large distances to these potentially habitable planets, the only way to explore them may be to send out one-way space missions. With current technology, spacecraft need fuel to travel.

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Science inquiry 6.1

Hot Jupiters

Hot Jupiters are a class of exoplanets that are similar in size and composition to Jupiter, the largest planet in our solar system, but have orbits that bring them very close to their host stars. As a result, they have extremely high temperatures, sometimes even higher than 700°C. Their short orbital periods make them easy to detect using current exoplanet detection methods.

Figure 6.40 The PEST Observatory

The Perth Exoplanet Survey Telescope (PEST), operated by amateur astronomer Thiam-Guan Tan, is an example of how backyard astronomy can contribute to significant scientific discoveries. Located in the southern suburbs of Perth, Western Australia, PEST is a small, privately owned telescope that has played a crucial role in the discovery and confirmation of over 108 exoplanets.

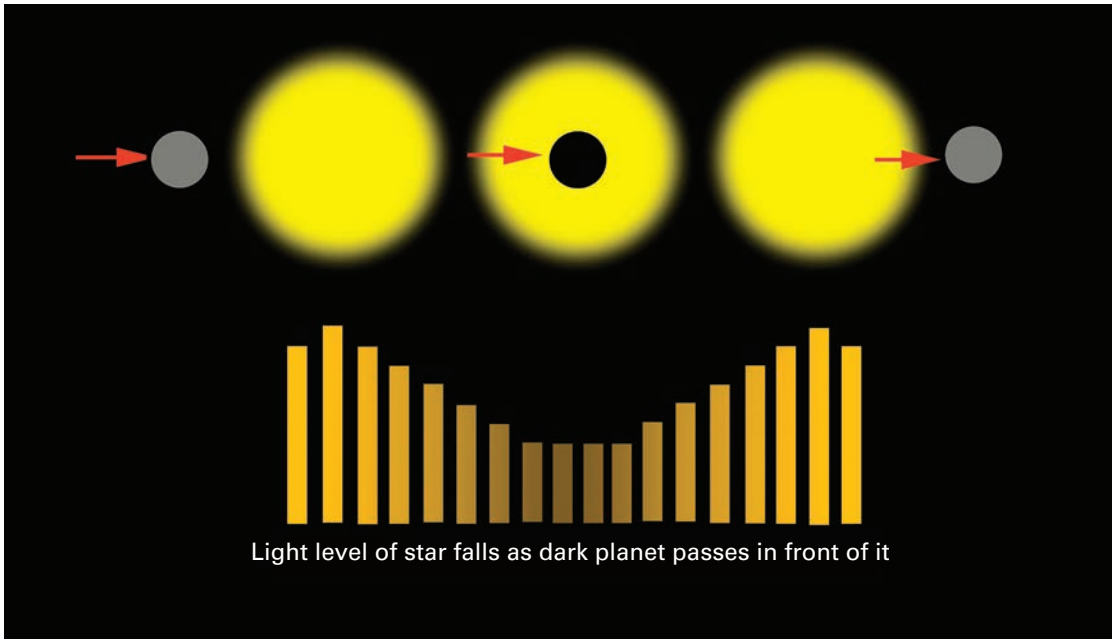

Figure 6.41 Astronomers use transit photometry to detect exoplanets.

To be able to accelerate very quickly, you need to take more fuel, but extra fuel makes the spacecraft heavier, decreasing the acceleration. Even if in the future we discover a way to travel large distances without carrying fuel, the journey to other star systems will still probably be much longer than a human lifetime. There are a few solutions to this problem. One might be to send a population of several generations of humans out on huge spacecraft to explore the stars. These explorers would have to deal with things like a changed physiology due to living in space. Another solution might be to send people away in suspended animation and wake them up when they get to their destination. A third solution might be to not send humans at all and instead send advanced robots or androids. It is not just a world of opportunities, but a universe of possibilities that awaits us!

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Explore! 6.5

Australian astrophysicists

Research the following Australian astrophysicists and their contributions to international astronomy:

- Doctor Abigail Allwood
- Professor Lisa Kewley
- Kirsten Banks
- Professor Brian Schmidt
- Professor Tamara Davis
- Doctor Jessie Christiansen.

Figure 6.42 Jessie Christiansen at Palomar Observatory in California

Section 6.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 6.3 questions

Remembering

1. **Define** a light year.
2. **Recall** the units used to measure parallax angle and star distance (for stars less than 100 light years away).

Understanding

3. **Explain** why an ambulance siren changes to a slightly lower pitch as it drives past you.
4. **Describe** what is meant by the term 'Goldilocks zone'. How does it apply to humans being able to live outside our solar system?
5. **Explain** how astronomers determined that the majority of galaxies we can observe are travelling away from us.

Applying

6. An astronomer collects data from a star in January and then again in July, and finds that its parallax angle is 0.8 arcseconds. **Calculate** the distance to the star. Express your answer in parsecs and light years.

Analysing

7. **Contrast** red shift and blue shift.

Evaluating

8. **Evaluate** the potential of humans finding a way to leave our solar system.

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6.4 The Big Bang

WORKSHEET
The Big Bang

Learning goal

At the end of this section, I will be able to:

1. Describe the major changes in the universe that have occurred since the Big Bang.
2. Describe the evidence that provides support for the acceptance of the Big Bang theory.

Big Bang
the rapid expansion of matter that marked the origin of the universe

singularity
a point at which infinitely dense matter occupies an infinitely small space

cosmic microwave background
electromagnetic radiation left over from the early stages of the universe

The **Big Bang** is a theory that most people have probably heard of and accept as the explanation of how the universe began. But how do we know what happened such a long time back, and what evidence have astronomers discovered to support it?

Evidence for the Big Bang

The Big Bang theory suggests that the universe began as a very uniform, hot, dense state which expanded rapidly 13.7 billion years ago. The observable universe that we can see today was compacted into a very small **singularity**. Three main pieces of evidence support the Big Bang theory:

- Almost all galaxies are red shifted, which means that almost all galaxies are travelling away from us. This suggests that the universe is expanding and that, if you extrapolate backwards in time, the universe had a beginning.
- The abundance of smaller elements in the universe is consistent with them being created in a Big Bang and not inside stars through nuclear fusion.
- Radiation left over from the early universe, called **cosmic microwave background**, is the same in every direction and consistent with the rate of cooling calculated from a Big Bang explosion.

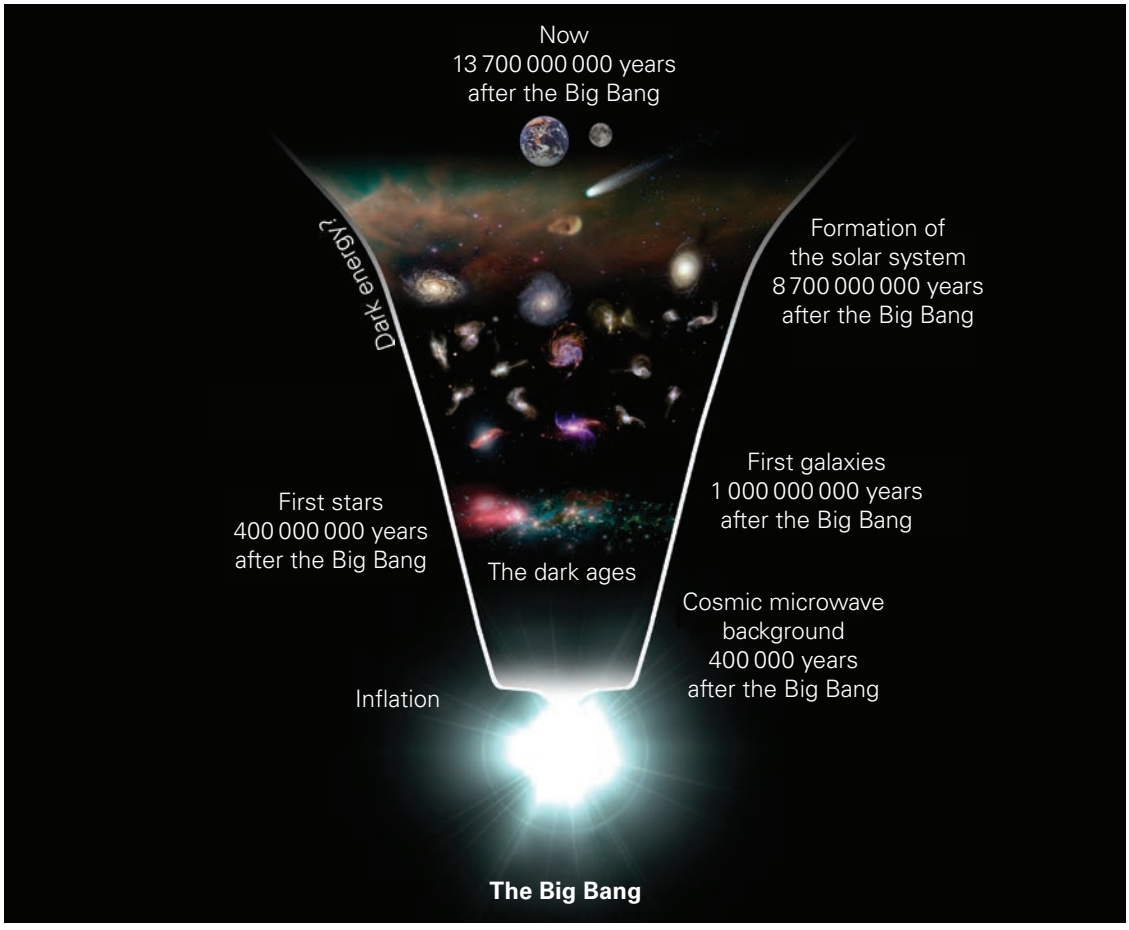

Figure 6.43 The history of the universe

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In the beginning

The Big Bang theory suggests that initial state of the universe was a very hot and very dense **plasma**, a boiling soup of fundamental particles and forces, that extended uniformly in all directions, perhaps infinitely. From this state, 13.7 billion years ago the universe expanded everywhere in a big explosion that stretched everything apart. The entire observable universe that we see today was compressed into a tiny region called a singularity. In the first stage of the universe's existence, the first 300 000 or so years, atoms could not yet exist because of the extreme density and temperature of the young universe. As the universe expanded, it became less dense and cooled to a point at which the fundamental particles and forces of nature became distinct. Around three seconds after the Big Bang, protons and neutrons combined to form the nuclei of the lightest elements: hydrogen and helium. The electrons still remained free in the plasma.

plasma
the ionised fourth state of matter, in which nuclei and electrons are separated

epoch of recombination
the point in time when electrons and ions could combine to form atoms

During this phase, all the **photons** emitted in the beginning were scattered by the sea of electrons and so the universe was opaque. Atoms were formed 380 000 years later, when the temperature finally cooled enough for atomic nuclei to capture electrons. This period of time is called the **epoch of recombination**. With the electron fog cleared, photons were no longer scattered and were free to travel the universe, which became transparent. These photons, the afterglow of the Big Bang, can be observed today as cosmic microwave background radiation.

Cosmic microwave background

Radiation refers to all frequencies of the electromagnetic spectrum, including gamma rays, X-rays, ultraviolet, visible light, infrared, microwaves and radio waves. Radiation from the Big Bang is still detectable today in the form of very low-frequency microwaves, known as cosmic microwave background (CMB).

CMB was discovered by accident in the 1960s, when two radio astronomers detected a faint, persistent buzzing from the sky. At first, they believed it was interference from their antenna, but they soon realised they had found evidence of ancient radiation left over from the early universe.

CMB is often described as the oldest light we can observe. It dates back to about 380 000 years after the Big Bang, when the universe had cooled enough for photons to travel freely through space. Since then, this light has continued to move through the universe, offering a snapshot of what it was like in its infancy – its temperature, density and tiny fluctuations that eventually gave rise to galaxies and other cosmic structures.

Light always travels in straight lines unless something interferes with it. Just as a tennis ball thrown in space would keep moving in a straight path, photons do the same. Because light takes time to travel, we are always looking into the past when we observe distant objects. For example, the light from Alpha Centauri takes 4.4 years to reach Earth, so we see it as it was 4.4 years ago. When we observe CMB, we are looking back nearly 13.7 billion years, to the earliest observable moment in the universe's history.

Did you know? 6.6

Detecting the first light

The photons emitted in the early stages of the universe are red shifted. This has resulted in the light becoming less intense and less visible to our instruments.

In the early universe, the expansion was much faster than it is today, causing the light from early photons to be red shifted even further. The light from the early universe has also been absorbed and scattered by clouds of gas and dust, making it even more difficult to detect.

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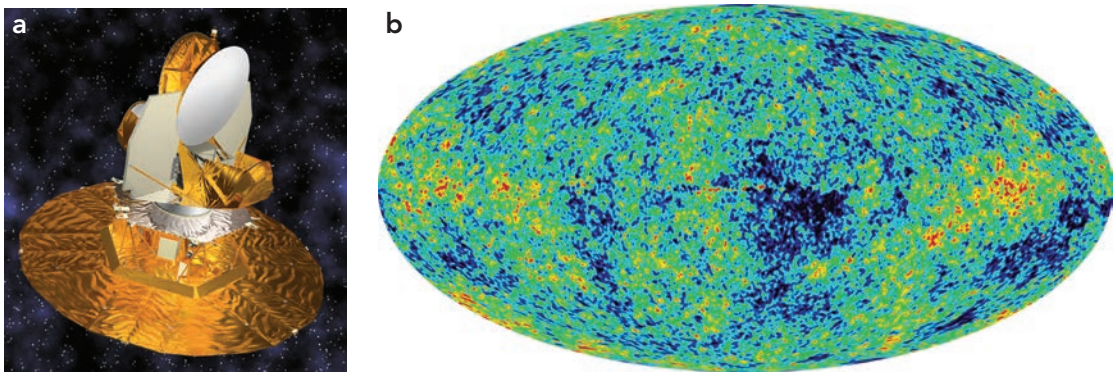

Figure 6.44 The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft **(a)** operated in the early 2000s to collect temperature data from the cosmic microwave background **(b)**.

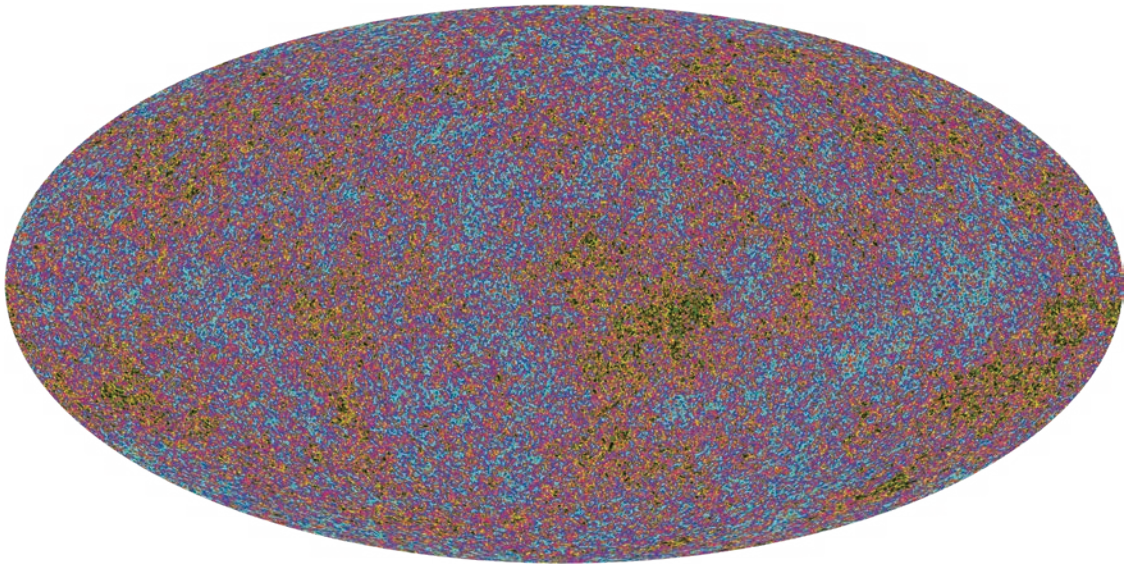

Figure 6.45 Data collected from the European Space Agency's Planck satellite between 2009 and 2013 mapped the cosmic microwave background. This is our oldest view of the universe.

Quick check 6.7

1. **Explain** why we cannot see photons emitted in the earliest stages of the universe.

Formation of stars and galaxies

In the first few minutes after the Big Bang, the universe was composed of a hot, dense plasma of mostly hydrogen and helium. As the universe expanded and cooled, matter began to come together through gravitational attraction to form larger structures such as gas and dust clouds. Within these clouds, the density and temperature increased, leading to nuclear fusion and the formation of stars.

Over time, stars produced elements heavier than helium in their cores, which then formed into planets, asteroids and other objects when these stars exploded as supernovas or shed their outer layers as planetary nebulae. The Sun has been found to contain a number of these heavier elements, so it is thought that it and the planets of the solar system formed from a nearby supernova that exploded in the early stage of the universe. Because the Sun formed from the remains of an earlier star, it is called a secondary star. Large collections of stars in the early universe clustered together to form galaxies. These galaxies have continued to move apart as the universe expands.

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Dark matter and dark energy

One of the great mysteries that astronomers are currently working on is finding out about dark matter and dark energy.

Gravity is a property of mass, or matter. All objects have gravity, and the more mass, the more gravity. Astronomers have measured the amount of gravity in the universe indirectly; that is, they can measure it by observing the effects that it has on things around it. They have found that there is more gravity in the universe than the amount that can be attributed to visible matter. Astronomers theorised that there must be some other type of matter causing this extra gravity, calling it **dark matter**. In 1965, Vera Rubin hypothesised that dark matter existed when she observed a difference in the predicted and observed motion of galaxies. She concluded that invisible gravity sources were pulling planets and stars in certain directions.

dark matter matter that does not emit light and is responsible for unidentified gravity in the universe

dark energy a theoretical force responsible for accelerating the expansion of the universe

Try this 6.3

Animating the Big Bang

Use animation or comic strip software to create an explanation of the Big Bang for other year 10 students.

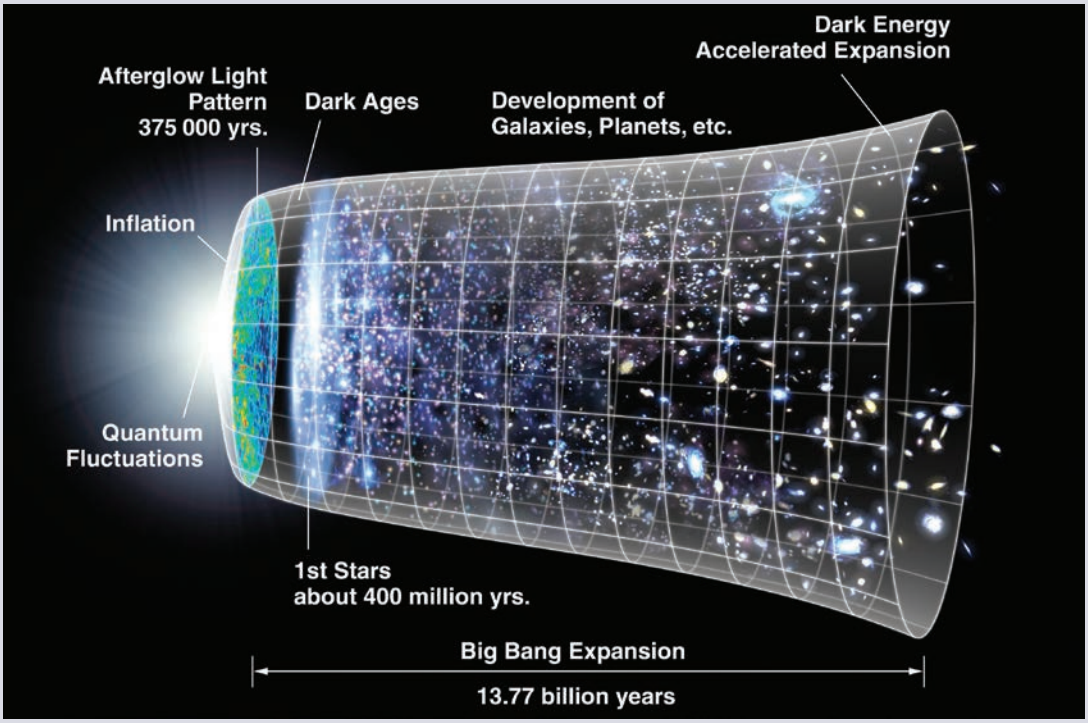

Figure 6.46 A representation of the universe over 13.77 billion years

We know that the universe is expanding because light from other galaxies is red shifted. But galaxies are not just moving away from all other galaxies; they are doing so at an accelerating rate. It seems that there is some sort of unobservable pressure that is making the universe expansion rate accelerate. This unknown pressure has been termed **dark energy**. It is amazing to think that in the future, the universe may have expanded so vastly that all other galaxies will be outside our observable universe, so we will not actually be able to see anything beyond our own galaxy!

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Explore! 6.6

Validating the existence of dark matter

Vera Rubin's discovery of the existence of dark matter was validated through multiple lines of evidence. Research how the following pieces of evidence helped to support the existence of dark matter:

- rotation curves
- gravitational lensing
- cosmic microwave background radiation
- numerical simulations.

Figure 6.47 American astronomer Vera Rubin

Explore! 6.7

The search for extraterrestrial intelligence

Given the immense size of the universe, it seems likely that life has also arisen in other places in the universe. The SETI program (Search for Extraterrestrial Intelligence) was developed to monitor radio waves from space to potentially find other intelligent life in our galaxy.

1. Research SETI and describe the projects currently under way.
2. Describe the type of data that is collected and explain what we can learn from it.
3. If you are interested, join SETI@home and let your computer download and analyse data to contribute to the SETI program.

Did you know? 6.7

The observable universe

The observable universe refers to the part of the universe that can be observed through telescopes and other technology, given the speed of light and the age of the universe.

Currently, it has an estimated diameter of about 93 billion light years and contains approximately two trillion galaxies, each containing billions of stars and other celestial objects. It also contains larger structures such as galaxy clusters and cosmic microwave background.

The observable universe is limited by the horizon, which is the maximum distance that light has had time to reach us since the Big Bang. Beyond the horizon, the universe is thought to continue, but it cannot be observed directly.

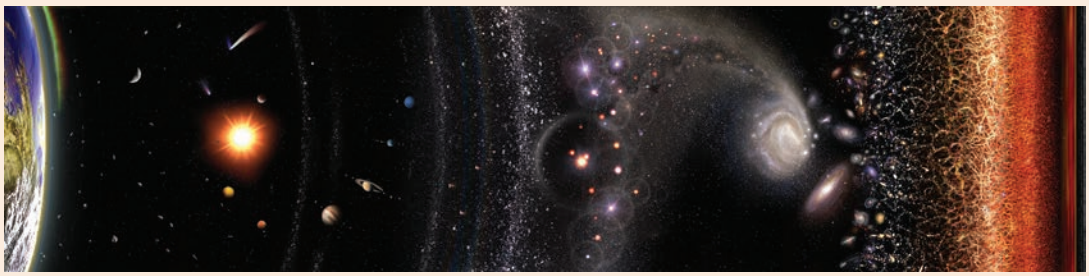

Figure 6.48 A map of the observable universe. From left to right, the known celestial bodies are arranged according to their proximity to Earth. In the far right, cosmic microwave background radiation is present, as the furthest and oldest thing we can see.

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Age of the universe

Edwin Hubble discovered that other galaxies exist in the 1920s by observing that many 'clouds' of dust and gas were actually extremely distant collections of stars. He noticed that these distant galaxies were different sizes and concluded that the smaller ones must be further away. While this assumes that all galaxies are the same size, which they are not, it is nevertheless a pretty good approximation of these distances.

Hubble calculated the **recessional velocity** of the galaxies (that is, the speed at which they are travelling away from us) by recording the red shift of their spectra. The further the spectral lines are shifted towards red, the faster the galaxy is moving. Hubble found that the further a galaxy is from us, the faster it is travelling away from us, so he proposed a relationship between distance and recessional velocity. This relationship is called **Hubble's law** and is given by the formula:

recessional velocity the rate at which a star is moving away from Earth

Hubble's law the farther away a galaxy is from Earth, the faster it is moving away from us

$$v = H_0 D$$

where v is the recessional velocity, D is the distance from Earth and H_0 is a constant that we call Hubble's constant. Hubble's original measurement of H_0 was 500 kilometres per second per megaparsec (abbreviated as km/s/Mpc or more formally as km s^{-1} Mpc^{-1}), or 160 km s^{-1} per million-light-years. However, over time, the constant has been measured more and more accurately, and the current value is 73.8 km s^{-1} Mpc^{-1}.

Figure 6.49 Edwin Hubble, one of the most important astronomers of all time

Hubble's law demonstrates two points:

- The universe is expanding everywhere and in all directions.
- The expansion of the universe given by the Hubble constant can be traced backwards to where $D = 0$ to find the age of the universe.

Misconceptions about the Big Bang

A few misconceptions arise about the Big Bang – partly because of the name 'Big Bang' and partly because it is just a difficult concept to comprehend.

One slightly misleading concept is the idea of the singularity that existed before the Big Bang. 'Singularity' might sound like it means that the whole universe was located at a single point and that the expanding universe has an edge. In fact, the universe extends beyond our observable region, perhaps forever and with no edge. In the past, everything was so compressed that our observable region was effectively a point compared to today, and this is what we call the singularity. Essentially, the Big Bang did not happen in a specific spot; it happened everywhere. A more accurate description would be to call it the 'big stretch'.

Making thinking visible 6.2

The complexity scale: The Big Bang

1. Write down any information you have about the Big Bang, including facts, observations and ideas.
2. Place each statement on the complexity scale, which ranges from simple to complex.
3. Provide an explanation for why you chose to place each statement where you did on the complexity scale.
4. Reflect on the exercise and consider what new insights and questions you have gained about the Big Bang.

The *The complexity scale* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Practical 6.3

Modelling the expanding universe

Aim

To model the expanding universe with a balloon and evaluate the limitations of the model.

Materials

- balloon
- small dot stickers
- permanent marker
- piece of string around 40 cm long
- ruler
- paperclip
- stopwatch

Method

Part 1: Prepare the results table

Draw the table shown in the results section into your science book.

Part 2: Set up the model

1. Partially blow up the balloon to about 10 cm in diameter and secure the end with a paperclip (do not tie the balloon as you will need to further inflate it later).
2. Stick six dots on the balloon at random points and label one as H (for home) and the others as A, B, C, D and E. The home dot represents the Milky Way, and the other dots represent neighbouring galaxies. You may add more than five neighbouring galaxy dots if you like.

Part 3: Measure the variables

1. Use the string and ruler to measure the distances HA, HB, HC, HD and HE. Record them in the results table under D_1.
2. Remove the paperclip, then fully inflate the balloon, timing how long it takes you to do this with the stopwatch. Tie the balloon off.
3. Measure the five distances again and record them in the results table under D_2.

Results

Position on balloon	D_1 (cm)	D_2 (cm)	Mean speed (cm s^{-1})
HA			
HB			
HC			
HD			
HE			

Data processing

1. Calculate the mean speed at which each dot was moving away from the home dot in the time (t) it took you to blow up the balloon, by using mean speed $= \frac{D_2 - D_1}{t}$.
2. Draw a scatter plot to analyse the relationship between mean speed (on the vertical axis) and the D_2 (on the horizontal axis).
3. Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.

continued …

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Discussion

1. Describe the trend or pattern that was found when the line of best fit was applied to the graph. What type of relationship was found?
2. Suggest how you apply this relationship to understanding the movement of galaxies and expansion of the universe.
3. Predict the misconception that might arise if you drew the galaxies on with the marker rather than using stickers.
4. Evaluate the limitations of using a balloon as a model for three-dimensional space, and suggest a better model.
5. Can a valid conclusion regarding the expansion of the universe be drawn from modelled experiments such as this one? Support your statement using data and limitations of the model.
6. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the reliability or validity of the data.

Section 6.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 6.4 questions

Remembering

1. **Recall** the age of the universe.
2. **State** the assumption that Hubble made about galaxies and what he concluded about galaxies that appeared smaller than others.

Understanding

3. **Explain** the concept of the observable universe.

Applying

4. An astronomer observed a distant galaxy to be travelling at a recessional velocity of 370 km s^{-1}. Use the current value of Hubble's constant (73.8 km s^{-1} Mpc^{-1}) to **calculate** its distance from us. Give your answer in megaparsecs (Mpc).

Analysing

5. **Organise** the following parts of the electromagnetic spectrum from lowest frequency to highest: infrared, gamma, radio, X-ray, microwave, visible, ultraviolet.

Figure 6.50 The Orion Nebula in a composite image of visible light and infrared, taken by the Hubble Space Telescope.

Evaluating

6. **Create** a drawing with labels to demonstrate the enormous size of the universe.

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Chapter review

Chapter checklist

Success criteria		Linked questions
6.1	I can describe Aboriginal and Torres Strait Islander Peoples' knowledges of celestial bodies and explanations of the origin of the universe.	6
6.1	I can describe recent advances in astronomy.	11
6.1	I can identify the different technologies used to collect astronomical data and the types of data collected.	12
6.2	I can describe how stars' light spectra and brightness are used to identify compositional elements of stars, their movements and their distances from Earth.	7
6.3	I can describe the major components of the universe.	16
6.4	I can describe the major changes in the universe that have occurred since the Big Bang.	17
6.4	I can describe the evidence that provides support for the acceptance of the Big Bang theory.	3

Go online to access the interactive chapter review

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Recall** the evidence that Ptolemy used to explain his geocentric model.
2. **Recall** the evidence that Copernicus used to disprove the geocentric model.
3. **Recall** the evidence that supports the Big Bang theory.
4. **Recall** how parallax can be used to measure distances in space.
5. **Define** 'red giant'.
6. **Recall** whether the Sun is a matriarchal or patriarchal spirit in many First Nations Australian cultures.

Understanding

7. **Describe** the relationship between star brightness, size and length of lifetime. Explain why this is the case.

Figure 6.51 An artist's engraving of Ptolemy looking to the sky

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8. Astronomers have found that the spectral lines from a distant galaxy are red shifted. **Summarise** what this tells us about the galaxy and what it implies about the universe.
9. **Explain** why we cannot see photons emitted in the earliest stages of the universe.
10. **Explain** how cosmic microwave background is considered evidence for the Big Bang.
11. **Describe** some recent advances in astronomy.

Applying

12. **Compare** optical and radio telescopes.
13. **Contrast** the heliocentric and geocentric models of the universe.

Analysing

14. An astronomer makes two observations of a star six months apart and measures a parallax angle of 0.1 arcseconds. **Calculate** the distance to the star. Convert your answer into light years and kilometres.

Evaluating

15. **Discuss** the chances of finding intelligent life elsewhere in the universe. Use evidence to justify your answer.
16. **Discuss** the major components of the universe.
17. **Discuss** the major changes that have occurred in the universe since the Big Bang.

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Data questions

The universe is home to billions of stars, many much larger and much brighter than the star we call the Sun. Figure 6.52 presents a selection of stars in our universe and shows their surface temperature and luminosity. As a reference, the Sun has a luminosity of 1 and a surface temperature of approximately 5800 K. The stars in Figure 6.52 belong to four different categories depending on their properties: the main sequence, white dwarfs, red giants and blue or red supergiants.

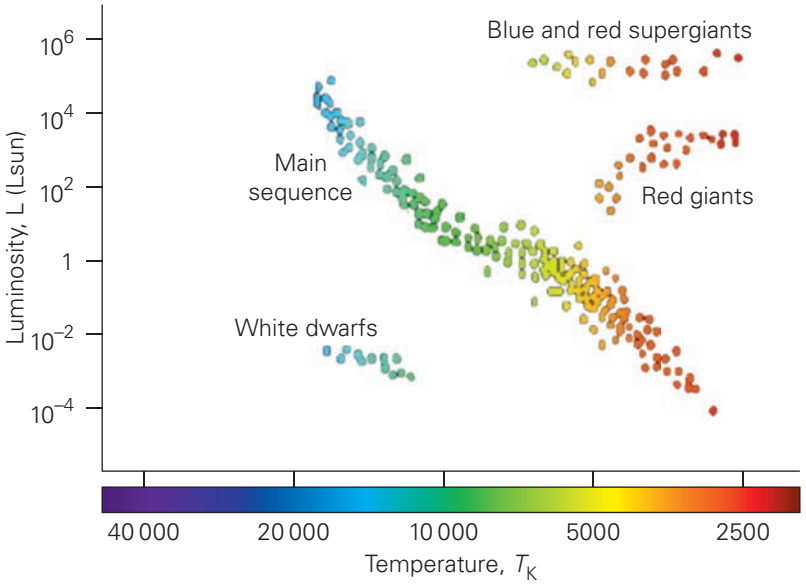

Figure 6.52 A Hertzsprung–Russell diagram illustrating the surface temperature and luminosity of various stars in the universe

1. **Identify** the category of star to which our Sun belongs.
2. **State** which category of star is most luminous.
3. The *x*-axis provides the star surface temperature in units of kelvin (°C = K − 273). Given that the surface temperature of the Sun is 5800 K, **calculate** the surface temperature in degrees Celsius.
4. **Identify** the trend of surface temperature and luminosity of stars in the main sequence.
5. **Contrast** the properties of white dwarfs and red giants.
6. **Identify** any patterns occurring in the properties of blue and red supergiants.
7. A large star has been discovered and classified as a main sequence star with a surface temperature of 25 000 K. **Deduce** the luminosity of this star compared to the Sun.
8. New data have suggested that this new star (from Question 7) is almost 100 000 years old. Its surface temperature is cooling, and it is becoming slightly more luminous. **Predict** the category this star will belong to as it leaves the main sequence.
9. **Compare** the properties of all four categories of star. Do you think the size of a main sequence star will ultimately determine whether it becomes a supergiant, giant or dwarf?

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STEM activity: Creating a representation of our solar system to scale

Background information

How do you create an image that shows, as accurately as possible, the distance between our Sun and Earth (150 million km)? Have you stopped to think about that tremendous distance? Why not represent our solar system to scale?

Humans are used to handling small numbers and units. We talk about centimetres, metres or kilometres; and minutes, hours, days, months or years. However, in astronomy we see tremendously large numbers in space and time which escape our understanding and are difficult for us to imagine. In this activity you are invited to create a representation of our solar system to scale to gain a better understanding of its size.

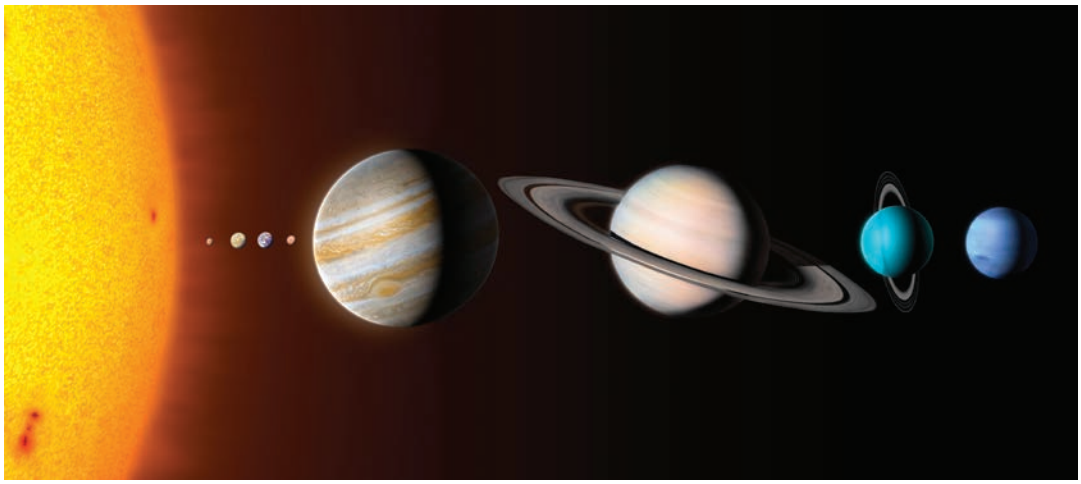

Figure 6.53 A representation of our solar system where the distances are not to scale, but the sizes are to scale

DESIGN BRIEF

Design a scale model of the universe and present this information in the form of a vlog (video blog or video log).

Activity instructions

The solar system is much bigger than most people think. In this activity you will collaborate in groups to create a representation of our planetary system to scale, using hands-on materials while recording your journey. The scale model must include all the planets and known dwarf planets. You will need to make sure that your scale model helps others gain a better idea of the vastness and true size of our solar system. To do this you will need to make sure that you find a way (for example, a formula) to convert distances and diameters of planets into something humans can comprehend. How do we do that?

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Here are a couple of suggestions:

- Imagine that we convert the distance from the Sun to our Earth from 150 million kilometres to 2 metres instead. Can you see how much easier it is to visualise and comprehend the 'metre' than the 'millions of kilometres'? Now you can repeat this same conversion for all planets on the solar system using the table provided. That will let you start comparing distances for these celestial bodies in a much more meaningful way. You can finally visualise the scale of the vastness of our solar system.
- Having the correct distances is a good step but does not give the full picture. Consider converting the diameter of our planet (12 756 kilometres) to a more manageable number. What about 10 centimetres? Then convert the diameters of the other bodies in our solar system.

Use your new measurements to create a two-dimensional version of the solar system, showing Earth and all other planets and dwarf planets. Record a vlog of all the stages of your two-dimensional solar system and edit this video to be used as an educational resource.

Suggested materials

Model

- large reel of measuring tape
- colouring pencils, cardboard and paper to create your planets
- protractor
- scissors
- movie-maker software and recording device

NOTE: You may need to use the school oval to really represent the distances involved.

Research and feasibility

1. Using the information in Table 6.4, research how you could create a formula to assist you to convert all values from millions of kilometres to more manageable units (metres or centimetres). What skills do you need to perform that task? Record all information on your vlog.
2. Discuss in your group the feasibility of presenting the scale model within the restrictions of school. List your ideas of how to demonstrate the vast size of the solar system.
3. Record your research and results as the Research and feasibility section of your vlog.

Design and sustainability

4. Analyse Table 6.4 and make a statement about how the orbital period of a celestial body is affected by its distance from the Sun. Explain your reasoning.
5. The dwarf planet Haumea has been described as 'eccentric' by its discoverers. Analyse the table and determine which bit of data shows how this dwarf planet is very different from other dwarf planets.
6. Planets orbit around the Sun in elliptical orbits.
   a) Compare and contrast the average distance of planets and dwarf planets from the Sun.
   b) How do the orbits of dwarf planets compare (visually) to the orbits of inner planets in our solar system? You can draw or sketch your answer if you like.

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7. Record your analysis as a 'Design and sustainability' section of your vlog.

Name of planet	Average distance from Sun (km)	Diameter (km)	Time to spin on axis (a day)	Time to orbit Sun (a year)	Distance scale (m)	Diameter scale (cm)
Mercury	57 900 000	4878	59 days	88 days		
Venus	108 160 000	12 104	243 days	224 days		
Earth	149 600 000	12 756	23 hours, 56 mins	365.25 days	2	10
Mars	227 936 640	6794	24 hours, 37 mins	687 days		
Jupiter	778 369 000	142 984	9 hours, 55 mins	11.86 years		
Saturn	1 427 034 000	120 536	10 hours, 39 mins	29 years		
Uranus	2 870 658 186	51 118	17 hours, 14 mins	84 years		
Neptune	4 496 976 000	49 532	16 hours, 7 mins	164.8 years		
Dwarf planets						
Ceres	413 900 000	950	9 hours, 5 minutes	4 years, 220 days		
Pluto	4 436 820 000 to 7 375 930 000	2370	6 days, 9 hours	248 years		
Haumea	5 260 000 000 to 7 708 000 000	1960 × 1518 × 996	4 hours	258 years		
Eris	5 665 500 000 to 14 634 000 000	2326	7 hours, 46 minutes	557 years		

Table 6.4 Some information about planets and dwarf planets within our solar system

Create

8. Create your two-dimensional solar system model. Make sure to include your scale.

9. Record the whole creation of your two-dimensional model in the 'Create' section of your vlog.

Evaluate and modify

10. Edit your vlog into a video file that can be shared.

11. Reflect on how effective your vlog is in demonstrating the vastness of our solar system.

12. Present your vlog to the class and discuss the use of vlogs to share information, and the effectiveness of its use.

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Chapter 7
Motion

Chapter introduction

Earth and everything on it are constantly moving. This chapter will explore the ways in which we can describe motion scientifically. This chapter explores distance, displacement, speed, velocity and acceleration and how these quantities can be displayed graphically. To change an object's motion, a net force is required. How forces affect motion are described by Sir Isaac Newton's three laws of motion. Newton's laws of motion provide the foundation of knowledge to analyse all forms of motion, from those used in sport to car crashes. They can also be used to analyse Aboriginal and Torres Strait Islander Peoples' technologies that make tasks more efficient.

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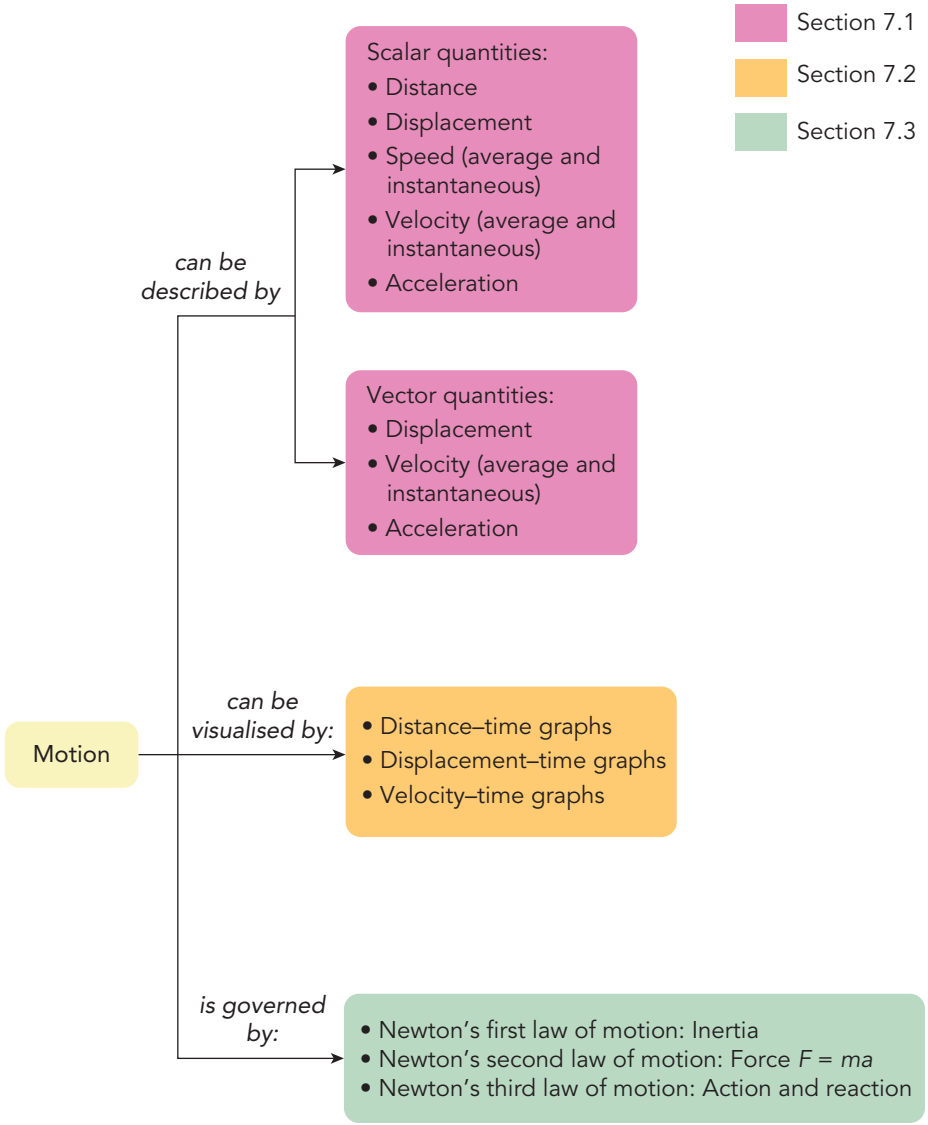
Chapter map



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Curriculum content

Physical sciences	
Motion can be quantitatively determined; quantities, including time, distance, displacement, speed, velocity and acceleration can be classified as scalar or vector; vector diagrams can be used to represent the magnitude and direction of motion	
• using vector diagrams to illustrate the difference between distance and displacement	7.1
• exploring the relationship between time intervals and distance or displacement to calculate speed, velocity and acceleration	7.2
Newton's laws of motion can be used to predict motion; the relationship between force, mass and acceleration of objects can be quantitatively determined	
• investigating Newton's three laws of motion	7.3
• applying Newton's three laws of motion to everyday applications, such as sport and driving	7.3
Collaborating and applying	
Illustrate how proposed scientific responses to contemporary issues may impact on society	
• examining how the recent use of female crash test dummies has shown women are at greater risk of injury in a car accident and consider implications for changing car safety features	7.3

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Glossary terms

acceleration (*a*)
average speed
average velocity
constant velocity
deceleration
displacement (*s*)
distance (*d*)
force
gradient
gravity
inertia
instantaneous speed
instantaneous velocity
mass
net force
Newton's first law of motion
Newton's second law of motion
Newton's third law of motion
origin
scalar
speed
stationary
terminal velocity
vector
vector diagram
velocity (*v*)
weight

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7.1 Describing motion

Learning goals

At the end of this section, I will be able to:

1. List scalar and vector quantities related to motion.
2. Distinguish between quantities of distance and displacement.
3. Convert units of speed and velocity between m s^{-1} and km h^{-1}.
4. Calculate and distinguish between quantities of speed, velocity and acceleration.

WORKSHEET Describing motion

Scalar and vector quantities

In this chapter, we will be describing motion with respect to magnitude and, in some cases, also the direction of motion. A **scalar** quantity is one describing only a magnitude of motion. Examples include distance and speed. A **vector** quantity describes both the magnitude and direction of motion. Examples include displacement, velocity, acceleration and force. The direction of the motion is noted for vector quantities – for example, displacement = 10 m west. Scalar and vector quantities that describe motion will be explored here.

scalar
a quantity having only magnitude

vector
a quantity having both magnitude and direction

distance (*d*)
a scalar quantity measuring the total length travelled

displacement (*s*)
a vector quantity describing the distance and direction of an object from its origin

Distance

In motion, **distance** is a scalar quantity that refers to the length an object travelled along a path. The symbol *d* is used to denote the distance an object has travelled, and it is measured in SI units (International System of Units) of metres (m). For example, the soccer ball in Figure 7.1 has travelled a distance of 20 metres (3 + 4 + 5 + 3 + 5).

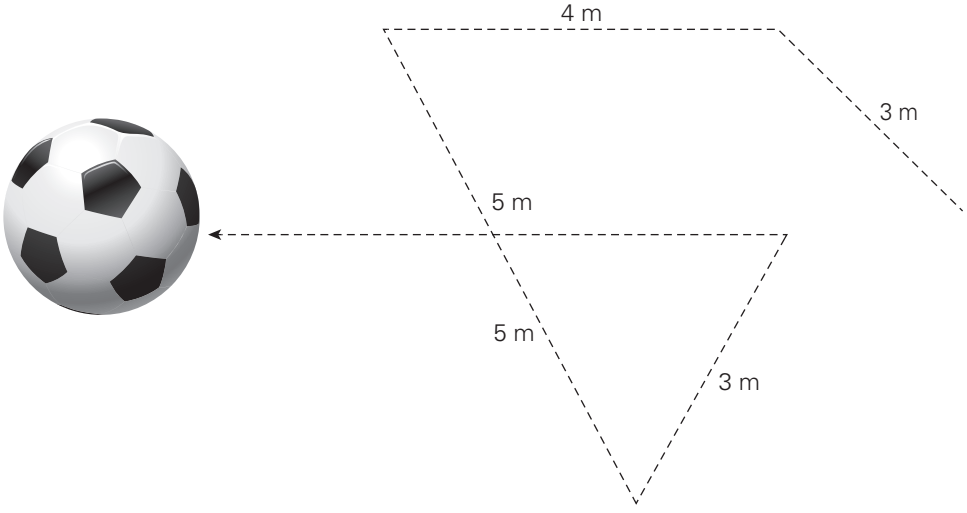

Figure 7.1 Distance travelled by a soccer ball

Displacement

Displacement is different to distance in that displacement is the length and direction of an object from its origin, regardless of its path. That is, an object's displacement is how far its final position is from its starting position and in what direction. Displacement is denoted by the symbol *s* and is measured in SI units of metres. It has both magnitude and direction, which makes displacement a vector.

Figure 7.2 Often a compass bearing is used to describe the direction of displacement, but simpler directions like left, right, up, down, backwards and forwards are sometimes used.

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Making thinking visible 7.1

Looking five times two: Perth in motion

1. Look at the image in Figure 7.3 for at least 30 seconds and let your eyes wander. List five objects you can see in the image, or that would occur within the pictured city, that might have motion.
2. Look at the image in Figure 7.3 again for at least 30 seconds. What words could be used to describe the motion of the objects that you have listed in Question 1? What units of measurement would be used?

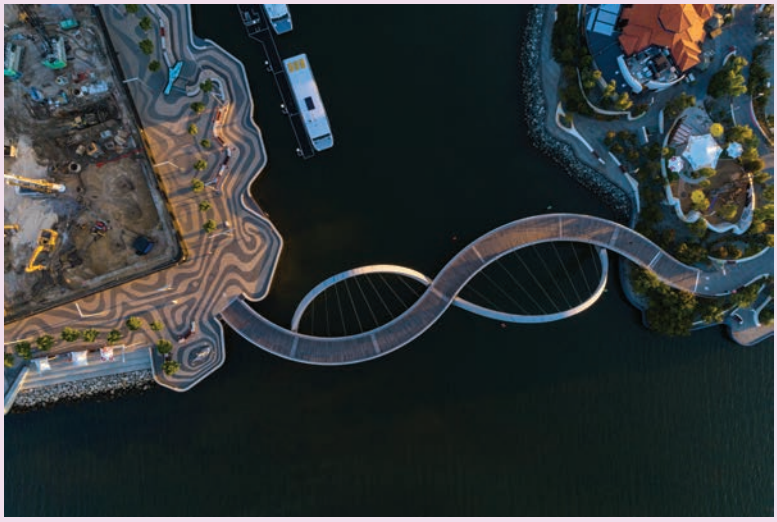

Figure 7.3 Motion in Perth city

The *Looking five times two* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

vector diagram
a diagram showing the magnitude and direction of a vector quantity

Figure 7.4 shows a **vector diagram** where the direction of motion matters. The starting point is the cross in the middle. A sailor knows they have sailed 20 kilometres (km), but they would not know where they are unless they know the direction in which they are sailing. Sailing 20 kilometres from the origin might mean the sailor ends up on any three of the different islands. Knowledge of direction matters!

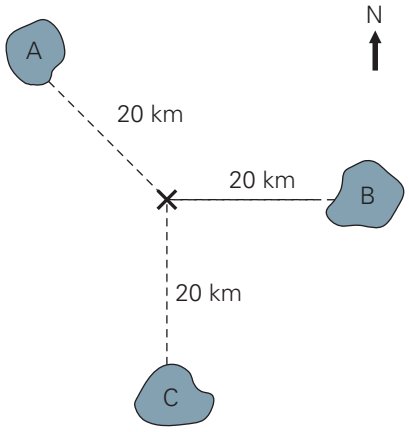

Figure 7.4 If the sailor ended up on island B, their displacement would be 20 km east from the origin.

VIDEO
Distance versus displacement

Distance versus displacement

Displacement provides different length information to that provided by distance. For example, a cat might walk 10 metres, but its displacement would be zero metres if it had returned to its original position. Knowing an object's displacement is often more helpful in finding it than knowing the entire journey the object took to get there.

Consider a cat's journey in the vector diagram in Figure 7.5. It walks east from point A to point B for six metres, and then west to point C for two metres. Its total distance covered is 6 m + 2 m = 8 m, but it has only displaced from its origin 6 m – 2 m = 4 m east. Distance provides information on the whole journey, while displacement gives information on the difference between the start and end positions.

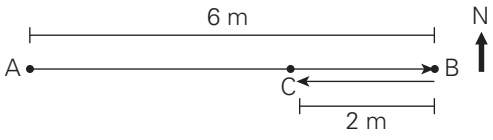

Figure 7.5 The walk described can be represented using arrows in a vector diagram, where the length of the arrow symbolises the magnitude, and the direction of the arrow shows the direction of motion.

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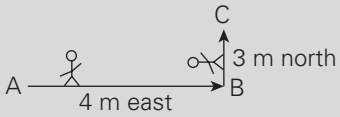
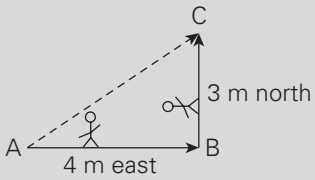
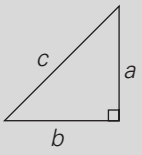
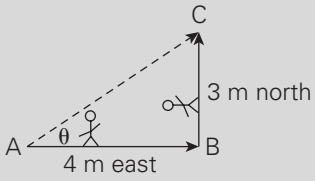
Worked example 7.1

Distance and displacement

A person walks 4 metres east and then 3 metres north. This can be represented in a simple vector diagram as follows.



1. Calculate the distance travelled by the person.
2. Calculate the displacement.

Working	Explanation
1. Distance	
$d = 3\text{ m} + 4\text{ m} = 7\text{ m}$	Add the two distances travelled to find the total distance that the person has travelled.
2. Displacement	
 Using Pythagoras's theorem, find the distance from A to C. $\text{AC} = \sqrt{4^2 + 3^2}$ $= \sqrt{16 + 9}$ $= \sqrt{25}$ $= 5\text{ m}$	Use Pythagoras's theorem to find the distance from A (the starting point) to C (the end point). $a^2 + b^2 = c^2$  $c = \sqrt{a^2 + b^2}$
Use trigonometry to find the direction of travel.  $\tan\theta = \frac{3}{4}$ $\theta = \tan^{-1}\left(\frac{3}{4}\right)$ $= 36.9°$ north of east Therefore, the displacement s is 5 metres 36.9 degrees north of east.	Remember that you also need the direction travelled from the starting position to the final position. We use inverse trigonometric functions to find unknown angles in right-angled triangles. Since we know the length of the opposite (O) and adjacent (A) sides in the triangle, we can use tan to solve for the angle: $\tan\theta = \frac{\text{O}}{\text{A}}$

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Did you know? 7.1

The first metre

Throughout history, many systems have been used to measure distance. Our metric system began during the French Revolution of the late 1700s when the French Academy of Sciences proposed the creation of a standard unit of length that could be used anywhere in the world. The meridional distance from the North Pole to the Equator passing through Paris was defined as 10 000 km, and the metre was defined as one 10-millionth of this distance. Examples of the 'provisional metre' were erected on walls in Paris in 1796–97 to inform the population of this new unit of measurement (it was provisional while final measurements of the meridian were being made). A one-metre platinum–iridium bar was produced in 1889 and kept in Paris as the international standard for the measurement. Prototype bars were made as a reference for other parts of the world. The original prototype is still displayed in France at the International Bureau of Weights and Measures, but in 1960 the definition of a metre was changed to one based on the wavelength of particular orange light radiated by krypton-86. Then in 1983, the General Conference on Weights and Measures redefined one metre as the distance that light travels through a vacuum in $\frac{1}{299\,792\,458}$ seconds.

Figure 7.6 The meridional distance from the North Pole to the Equator, passing through Paris

Quick check 7.1

1. **Compare** the terms 'distance' and 'displacement'.
2. A classmate travels between classrooms. From their initial classroom, they travel west 100 metres and then north 50 metres, where they arrive at the intended classroom.
   a) **Represent** this journey in a vector diagram.
   b) **Calculate** the distance travelled by the student with correct units.
   c) **Calculate** the displacement of the student, to the nearest metre. Remember to also give a bearing in your answer.
   d) The student then travels back to the initial classroom. **Calculate** their displacement with correct units.

Speed

speed
change in distance divided by time

We all use words or phrases to describe how quickly something travels, or maybe even to determine how long it will take to get from one place to another. **Speed** is a general term for how fast something travels. It is a measure of the distance (d) travelled, in SI units of metres (m), divided by the amount of time (t) it took to travel that distance, in SI units of seconds (s). Thus, speed is commonly measured in SI units of metres per second, which can be shown as m/s, or using index notation, m s^{-1}.

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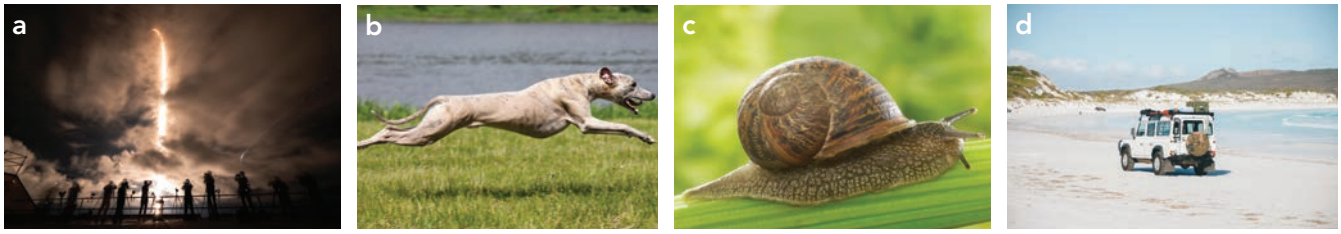

Figure 7.7 Examples of different speeds. **(a)** A rocket travels at a speed of at least 8 kilometres per second to reach space, **(b)** A whippet can reach a top speed of approximately 17 metres per second, **(c)** A snail moves in centimetres per minute, **(d)** We usually measure car speed in kilometres per hour.

Depending on the speed being observed, it is common to state speed in more appropriate units such as kilometres per hour (km h^{-1}), or even metres per minute (m min^{-1}), centimetres per hour (cm h^{-1}) or kilometres per second (km s^{-1}). The direction of speed is not considered, so it is therefore a scalar quantity.

Average versus instantaneous

Speed can be described as either **average speed** or **instantaneous speed**.

Average speed (*speed*) is the total distance an object travels divided by the time it takes to do so. The speed of the object may change as it moves. Instantaneous speed is the speed something is travelling at a given point in time.

Instantaneous speed can be determined using a radar gun or a speed detector. A speed detector calculates the average speed but over such a small timeframe that it is essentially capturing the speed at that instant, so it is called instantaneous. Another example of the measurement of instantaneous speed is a speedometer in a car.

Consider the examples of motion shown in Figure 7.7.

Speed is calculated as follows:

$$\text{average speed (m s}^{-1}\text{ or km h}^{-1}) = \frac{\text{distance travelled (m or km)}}{\text{time taken (s or h)}}$$

$$speed = \frac{d}{t}$$

A simple way to remember this equation is by using the average speed triangle shown in Figure 7.9.

Using the average speed triangle, you can derive formulas for:

- $speed = \frac{d}{t}$
- change in time $t = \frac{d}{speed}$
- change in distance $d = speed \times t$.

Figure 7.8 Speed detectors can capture the speed of an object in a fraction of a second.

average speed change in distance over a time interval

instantaneous speed the speed at a given point in time

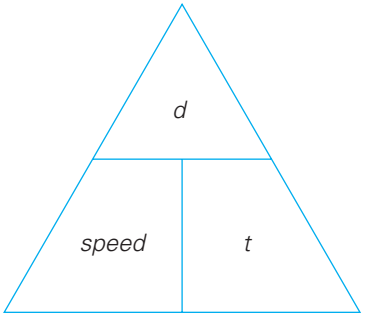

Figure 7.9 To use the average speed triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

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Worked example 7.2

Average speed

Consider two of the runners who are competing in a 100-metre sprint at a school athletics carnival. Runner 1 finishes in a time of 12.5 seconds. Runner 2 runs the race with an average speed of 7 m s^{-1}.

1. Determine who wins the race.
2. Calculate how long it takes runner 2 to cross the finish line. Round your answer to one decimal place.

Working	Explanation
1. Who wins?	
d = 100 m t = 12.5 s *speed* = ?	List the relevant information for runner 1.
$speed = \frac{d}{t} = \frac{100\text{ m}}{12.5\text{ s}}$ $= 8\text{ m s}^{-1}$	Calculate the average speed using the formula for average speed.
Runner 1: *speed* = 8 m s^{-1} Runner 2: *speed* = 7 m s^{-1} Since runner 1 has a higher average speed, they finish before runner 2 does. Therefore, runner 1 wins the race.	Compare the average speed of each runner.
2. Runner 2 time	
t = ? *speed* = 7 m s^{-1} d = 100 m	List the information you have for runner 2.
$t = \frac{d}{speed} = \frac{100\text{ m}}{7\text{ m s}^{-1}}$ = 14.3 s	Calculate the time taken for runner 2 to complete the race using a rearranged average speed formula.
It takes 14.3 seconds for runner 2 to complete the 100 metre race.	Interpret the solution, ensuring that you have correct units and decimal places.

Converting units

While the SI unit for speed is m s^{-1}, it is common to state speed in units of km h^{-1}, particularly for vehicle movement. It will be important to convert km h^{-1} to m s^{-1} later in this chapter, to use quantities such as velocity and acceleration. To make this conversion, kilometres should be converted to metres, and hours should be converted to seconds:

1 kilometre = 1000 metres

1 hour = 3600 seconds

$$1\ \frac{\text{km}}{\text{h}} = \frac{1000\text{ m}}{3600\text{ s}} = \frac{1}{3.6}\ \frac{\text{m}}{\text{s}}$$

Multiplying both sides by 3.6 and rearranging the sides to make 1 m s^{-1} the subject gives:

1 m s^{-1} = 3.6 km h^{-1}

To convert m s^{-1} to km h^{-1}, multiply by 3.6.

To convert km h^{-1} to m s^{-1}, divide by 3.6.

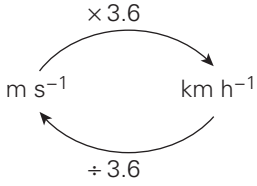

Figure 7.10 Converting m s^{-1} into km h^{-1}

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Quick check 7.2

1. A cat and a dog are in a 60-second race. Whoever travels the furthest in 60 seconds wins the race. The cat travels at an average speed of 4 m s^{-1}. The dog travels a total distance of 500 metres in that time.
   a) **Determine** whether the dog or the cat travels further and whether the dog or cat wins the race.
   b) **Calculate** the average speed of the dog, to two decimal places.

Try this 7.1

Converting speed

Consider the speed of a train in Western Australia travelling at 120 km h^{-1}. Convert this speed to m s^{-1}.

Is this result what you expected? Can you think of a scenario that would be appropriate to measure speed using m s^{-1} instead of km h^{-1}?

Did you know? 7.2

The light year

Light travels at a constant speed of 3×10^8 m s^{-1} in a vacuum (such as space) and almost as fast in air. The distance light travels in one year through space is one light year or 9.46 trillion kilometres. The light year is used to measure distances to stars and galaxies. For example, the brightest star in the night sky is Sirius, and it is 8.6 light years away. The nearest large galaxy is Andromeda, a mere 2.5 million light years away. Earth is 0.0000158 light years from the Sun. That means it takes eight to nine minutes for light from the Sun to reach Earth!

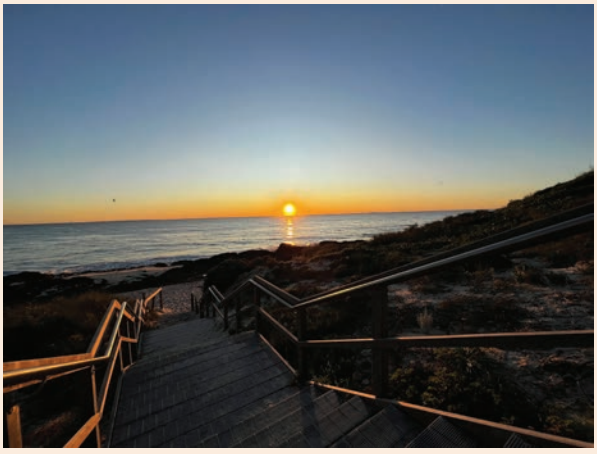

Figure 7.11 Light travels at 3×10^8 m s^{-1} in a vacuum.

Velocity

Velocity is a term used to describe how fast something travels in a particular direction. Like speed, the common units associated with velocity are m s^{-1} or km h^{-1}. However, unlike speed, velocity is a measure of the change in displacement of an object within a certain amount of time rather than a change in distance. Velocity includes more information than speed because it includes direction; it is used as a measure of how quickly something travels in a specific direction and is therefore a vector quantity. For example, aeroplane pilots and ship captains need to know their velocity so they can accurately navigate towards their destination. Skydivers are also very aware of their direction as they plummet towards the ground. They reach a **terminal velocity** when the downward force of gravity on the skydiver is balanced by the upwards force of air friction, so they are no longer accelerating. They have reached their maximum velocity in the direction of Earth!

velocity (v) change in displacement divided by change in time

terminal velocity the maximum speed reached by a free-falling object

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instantaneous velocity the velocity of an object measured at a particular moment in time

average velocity the rate at which an object is displaced or changes position over a time interval

Calculating velocity is similar to using the formula for speed, except distance travelled is replaced by displacement. As with speed, velocity can be classified as **instantaneous velocity** or **average velocity**.

Mathematically, velocity can be described in the following ways:

$$\text{average velocity (m s}^{-1}\text{ or km h}^{-1}) = \frac{\text{displacement (m or km)}}{\text{time taken (s or h)}}$$

$$v_{av} = \frac{s}{t}$$

Worked example 7.3

Average speed versus average velocity

Consider the triangle in Figure 7.12 between Perth, Albany and Kalgoorlie. Imagine two aeroplanes that need to get from Perth to Kalgoorlie. Plane 1 travels directly to Kalgoorlie. Plane 2 must stop in Albany before flying to Kalgoorlie. It takes both planes 2.00 hours to reach Kalgoorlie. Let's assume that Kalgoorlie is straight east of Perth.

1. Calculate the average speed of each plane.
2. Calculate the average velocity of each plane.
3. Determine which plane travels faster in the air.

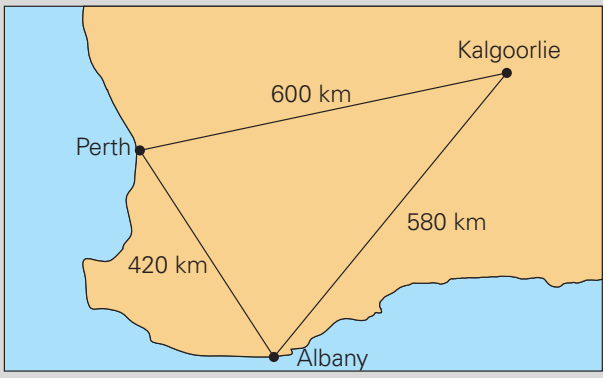

Figure 7.12 Travelling between Perth, Albany and Kalgoorlie

Working	Explanation
1. Average speed	
Plane 1: $speed = \frac{600}{2.00} = 300 \text{ km h}^{-1}$ Plane 2: $speed = \frac{(420 + 580)}{2.00} = \frac{1000}{2.00} = 500 \text{ km h}^{-1}$	For average speed, use this formula: $speed = \frac{d}{t}$
2. Average velocity	
Plane 1: $v_{av} = \frac{600}{2.00} = 300 \text{ km h}^{-1}$ east Plane 2: $v_{av} = \frac{600}{2.00} = 300 \text{ km h}^{-1}$ east	For average velocity, use this formula: $v_{av} = \frac{s}{t}$
3. Comparing speeds	
Plane 2 is faster in the air.	The plane with the greater average speed travels faster as it covers more ground in the same amount of time.

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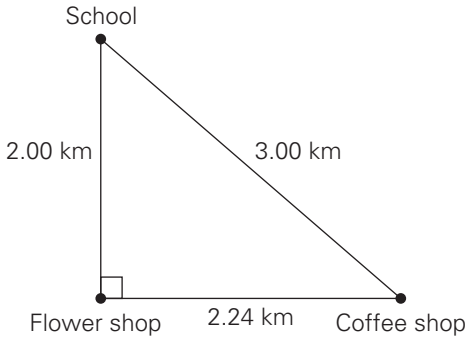
Quick check 7.3

Two students, Leon and Mira, leave school to meet at the local coffee shop for a hot chocolate after school. Leon decides to jog to the coffee shop, but also stops at a flower shop along the way. Mira decides to walk from school directly to the coffee shop. They arrive at the coffee shop at the same time, 30 minutes after they leave school. Use the diagram to answer the following questions.



1. **Calculate** how much further Leon travels than Mira.
2. If it takes them both 30 minutes to reach the coffee shop, **calculate**:
   a) Mira's average speed
   b) Leon's average speed
   c) their average velocities.

Acceleration

Acceleration describes the situation where an object speeds up (accelerates) or slows down (decelerates). **Acceleration (*a*)** is correctly defined as the change in velocity divided by time, and it is measured in SI units of m s^{-2}. Just as velocity provides directional information, acceleration provides directional information too and is a vector quantity.

acceleration (*a*) the change in velocity of an object over time

stationary not moving

deceleration when an object is slowing down

constant velocity when an object is travelling at the same speed without changing direction

Consider a **stationary** bus at a traffic light; we would say that it has an initial velocity of 0 km h^{-1}. Imagine that when the light turns green the bus 'speeds up' to 40 km h^{-1} in the next five seconds. This change in velocity means that the bus has an acceleration. Similarly, if the bus was moving and put on the brakes to 'slow down', this is known as **deceleration** or negative acceleration. If the bus is travelling at a **constant velocity** – that is, not speeding up, slowing down or changing direction – then its acceleration is zero. That is, there is zero change in its velocity over that time.

Acceleration can be calculated as follows:

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}} = \frac{\text{final velocity } (v) - \text{initial velocity } (u)}{\text{time taken}}$$

$$a = \frac{v - u}{t}$$

WORKSHEET Scalar and vector quantities

Using the acceleration triangle in Figure 7.13 is another helpful way to remember the formula for acceleration.

Using this acceleration triangle, you can derive formulas for:

- acceleration $a = \frac{v - u}{t}$
- time taken $t = \frac{v - u}{a}$
- final velocity $v = u + at$
- initial velocity $u = v - at$

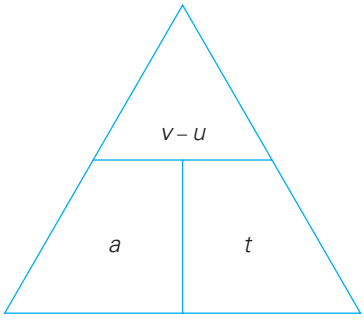


Figure 7.13 To use the acceleration triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

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Worked example 7.4

Acceleration

Consider the motion of a dirt bike.

1. If it speeds up from rest to 54 km h^{-1} in a straight line in 3.0 seconds, calculate the acceleration.
2. If that same bike travelling at 54 km h^{-1} comes to a stop in a straight line within 5.0 seconds, calculate the acceleration.
3. If better brakes were installed on the bike, it could decelerate at a quicker rate of 10 m s^{-2}. Calculate how long it would take to stop if it was initially travelling at a speed of 72 km h^{-1}.

Figure 7.14 A dirt bike in motion

Working	Explanation
1. Acceleration	
$u = 0$ m s^{-1} $v = 54$ km $h^{-1} = 15$ m s^{-1} $t = 3.0$ s $a = ?$	List the information you have. Since the bike begins at rest, the initial speed is zero. Recall that to convert from km h^{-1} to m s^{-1}, we divide by 3.6.
$a = \frac{v-u}{t} = \frac{(15-0)}{3.0} = 5.0$ m s^{-2}	Calculate using the acceleration formula by substituting in all the known values.
The bike accelerates (speeds up) at a rate of 5 m s^{-2} (5 metres per second, every second).	Interpret the answer.
2. Negative acceleration (deceleration)	
$u = 54$ km $h^{-1} = 15$ m s^{-1} $v = 0$ m s^{-1} $t = 5.0$ s $a = ?$	List the information you have. In this example, the bike has an initial speed of 54 km h^{-1} and a final velocity of 0 km h^{-1}.
$a = \frac{v-u}{t} = \frac{(0-15)}{5.0} = -3.0$ m s^{-2}	Substitute the known values.
Since there is a negative acceleration, the bike is decelerating at a rate of 3.0 m s^{-2}.	Interpret the solution and remember to include the correct units.
3. Faster stopping	
$a = -10$ m s^{-2} $u = 72$ km $h^{-1} = 20$ m s^{-1} $v = 0$ m s^{-1} $t = ?$	List the known information.
$-10 = \frac{(0-20)}{t}$	Substitute the values into the acceleration formula (or use the time formula from the acceleration triangle).
$t = \frac{-20}{-10} = 2.0$ s	Rearrange so that the unknown is the subject of the equation.
It takes the bike 2.0 seconds to decelerate from 72 km h^{-1} to rest.	Interpret the solution.

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Try this 7.2

Car acceleration

Next time you are in a car and travelling in a straight line, use the stopwatch on your phone to time the change in speed. Get the driver to read the speedometer to capture the instantaneous speed. Calculate the acceleration of the car under different circumstances using the formula for average acceleration in the following table. Remember not to distract the driver when doing this.

Test	Initial velocity	Final velocity	Time taken	Acceleration
Example:	0 km h^{-1} = 0 m s^{-1}	10 km h^{-1} = 2.8 m s^{-1} (divide by 3.6 to convert)	5 s	$a = \frac{(2.8 - 0)\text{ m s}^{-1}}{5\text{ s}} = 0.56\text{ m s}^{-2}$
1				
2				
3				

Quick check 7.4

1. **Define** the terms 'acceleration', 'deceleration' and 'constant velocity'.
2. An object increases its speed from 5.2 m s^{-1} to 7.7 m s^{-1} in 4 seconds.
   a) **Calculate** the acceleration of the object.
   b) Assume that the object could decelerate at a rate of 1.5 m s^{-2}. **Calculate** the time it would take for the object to stop if it was initially travelling at a speed of 10 m s^{-1}. Round your answer to two decimal places.

Explore! 7.1

Speed limits in Australia

It might be surprising to learn that prior to 1967, some roads in Australia had no speed limit at all! Over the decades since, road speed limits have been installed and updated to improve the road safety of drivers and pedestrians. In the 1980s, the maximum speed limit in some built-up areas such as school zones was decreased to 40 km h^{-1}, and there are proposals to decrease this further to 30 km h^{-1}, as is common in some other countries in the world.

Figure 7.15 Speed limits in school zones in Australia are typically 40 km h^{-1} at set times on school days.

Explore the National Road Safety Week website as a starting point to gather some data. Construct an argument, supported by data, for a campaign to reduce speed limits in school zones from 40 km h^{-1} to 30 km h^{-1}.

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Practical 7.1

Ramps and cars

Aim

To investigate the effect of ramp height on the average velocity (or acceleration) of a crash trolley or model car.

Materials

- ramp at least 90 cm long
- stopwatch
- metre ruler
- books or blocks that can be used to make a ramp
- crash trolley or model car

Planning

1. Develop a hypothesis by predicting how a change to the height of the ramp will affect the average velocity (or acceleration) of a model car.
2. Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.

Method

Part 1: Prepare the results table

1. Copy the results table into your science book.
2. Identify the independent variable and state it in the table.
3. Identify the dependent variable and state in the table.

Independent variable: _____	**Dependent variable:** _____			
	Trial 1	**Trial 2**	**Trial 3**	**Mean**

Part 2: Collect the data

1. Set up the ramp as shown in Figure 7.16.

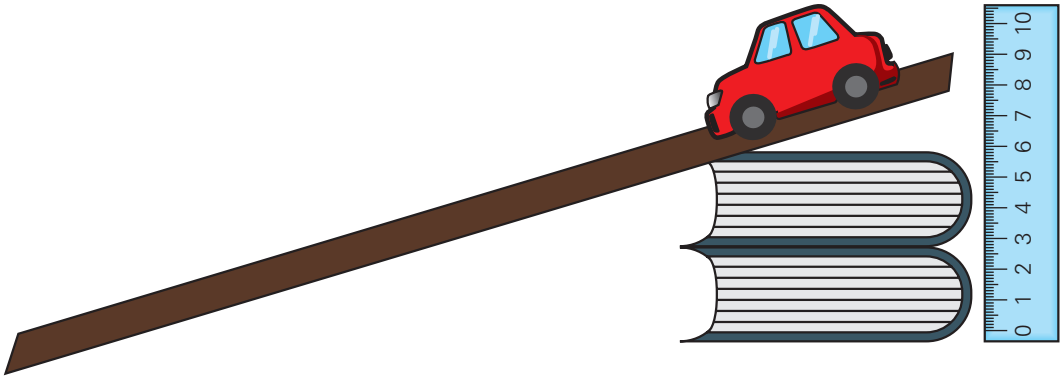

Figure 7.16 Experimental set-up

continued …

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2. Measure the height of the ramp.
3. Use the stopwatch to measure how long it takes for a crash trolley or model car to roll down the ramp. Record the results in the results table.
4. Repeat steps 2 and 3 three times so you can calculate the mean of the results.
5. Repeat steps 3 and 4 using some different heights and record your results in the table.

Results

1. Calculate the average time taken for the car to roll down the ramp. (If you are finding the acceleration, then you will need to decide how to calculate it.)
2. Draw a scatter plot to analyse the relationship between the height and the velocity (or acceleration).
3. Insert a copy of your graph below the results table in your science book.

Discussion

1. Describe the effect of different ramp heights on the mean velocity (or acceleration) of a model car.
2. Describe any limitations of your investigation and how these may have affected your results.
3. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the reliability or validity of the data.

Conclusion

1. Make a claim about how increasing the height of the ramp can affect velocity (or acceleration).
2. Support your statement by referring to your experimental data.
3. Explain how the data support your statement.

Figure 7.17 How would the incline and height of this hill affect the speed of the longboarder?

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Section 7.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 7.1 questions

Remembering

1. **List** two scalar quantities.
2. **List** three vector quantities.
3. **Recall** the formula and unit for average acceleration in a straight line.

Understanding

4. The average top speed of an e-scooter is 40 km h^{-1}. If the e-scooter is already travelling at that speed, **calculate** how far will it travel in 3 minutes.
5. If a person walks at an average speed of 4 km h^{-1}, **calculate** how long it will take them to travel 50 metres, to the nearest second. HINT: First convert 4 km h^{-1} into m s^{-1}.
6. **Determine** the acceleration of a car travelling at a constant speed of 50 km h^{-1}.

Applying

7. A sprinter starts from rest. In the first 3 seconds they reach a velocity of 2 m s^{-1}. After the next 10 seconds they reach a velocity of 6.5 m s^{-1}.
   a) **Calculate** the average acceleration in the first 3 seconds, and round to two decimal places.
   b) **Calculate** the average acceleration in the last 10 seconds.
   c) **Identify** whether the sprinter's acceleration is greater in the first 3 seconds or the last 10 seconds.
8. A car starts from rest and accelerates at a constant rate of 5 m s^{-2} for 3 seconds.
   a) **Calculate** the final velocity.
   b) **Calculate** the average velocity. Because the velocity increases at a constant rate, you can do this by using $\frac{v_1 + v_2}{2}$ to find the average velocity.
   c) **Calculate** the displacement of the car after 3 seconds.
9. **Describe** why vector diagrams are useful when calculating vector quantities.

Analysing

10. **Distinguish** between speed and velocity.
11. **Contrast** average speed and instantaneous speed.
12. **Classify** the following motions as either acceleration, deceleration or constant.

Motion	Acceleration/deceleration/constant
A bike rider slowing down	
A textbook sitting on a desk	
A sprinter taking off at the start of a race	
A dog running forwards at 5 m s^{-1}	
A car crashing into a brick wall	
A car rolling down a hill and gaining speed	

Evaluating

13. Imagine you were trying to determine how efficiently your car uses petrol. **Discuss** if you would use distance travelled or displacement covered with one tank full.

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7.2 Graphing motion

Learning goals

At the end of this section, I will be able to:

1. Interpret distance versus time and displacement versus time graphs.
2. Calculate the velocity from a displacement versus time graph.
3. Calculate acceleration and displacement from a velocity versus time graph.

WORKSHEET Graphing motion

Quantities that describe motion, such as distance, displacement, speed, velocity and acceleration, can be calculated using mathematical equations. However, they can also be illustrated on journey graphs, which represent the information visually.

Distance–time graphs

Distance–time graphs display the total distance an object travels over time. The **gradient** of the line indicates the average speed of the object. Recall that:

gradient in physics, how quickly something changes, or the rate of change; the gradient of a graph is calculated as the rise over the run

$$speed = \frac{d}{t} = \frac{\text{rise}}{\text{run}}$$

Table 7.1 shows some shapes you may see on a distance–time graph. Note that distance–time graphs are always horizontal or increasing; they cannot be decreasing.

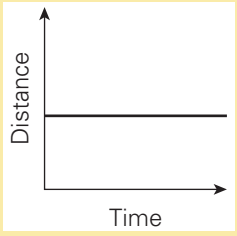
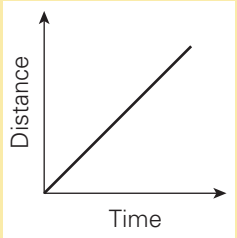
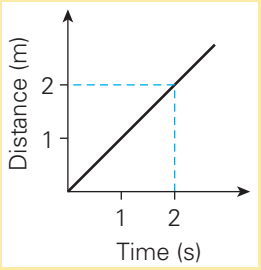
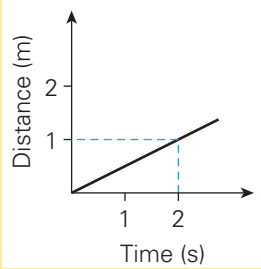
Shape	Explanation	Example
	Horizontal lines indicate that an object is stationary.	The $\frac{\text{rise}}{\text{run}}$ of horizontal lines is zero because the rise is 0 m. So the speed is 0 m s^{-1}.
	A straight line with a gradient indicates that the object is moving at a constant speed.	 $speed = \frac{\text{rise}}{\text{run}} = \frac{2\text{ m}}{2\text{ s}} = 1\text{ m s}^{-1}$  $speed = \frac{\text{rise}}{\text{run}} = \frac{2\text{ m}}{2\text{ s}} = 0.5\text{ m s}^{-1}$ The gradient of the first graph is steeper, which shows that object has a greater speed.

Table 7.1 Two shapes of distance–time graphs

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Worked example 7.5

Distance–time graph

Take a look at the distance–time graph that shows Elliott's walk in a straight line for 6 seconds.

1. Calculate his average speed during the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.
2. Identify when Elliott is travelling fastest.

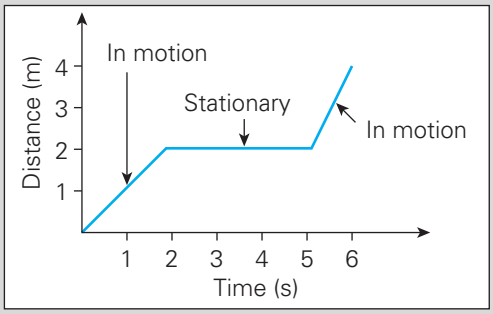

Figure 7.18 Distance–time graph of Elliott's walk

Working	Explanation
1. Average speed	
0 to 2 seconds: $speed = \frac{\text{rise}}{\text{run}} = \frac{(2-0)\text{ m}}{(2-0)\text{ s}} = \frac{2\text{ m}}{2\text{ s}} = 1$ 2 to 5 seconds: A horizontal line indicates that he is stationary. 5 to 6 seconds: $speed = \frac{\text{rise}}{\text{run}} = \frac{(4-2)\text{ m}}{(6-5)\text{ s}} = \frac{2\text{ m}}{1\text{ s}} = 2\text{ m s}^{-1}$	Select two points from each time interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the average speed.
2. Fastest interval	
He travels the fastest from the fifth to the sixth second.	The steeper line indicates a faster average speed.

Quick check 7.5

1. Analyse the distance–time graph of a moving object in Figure 7.19.
   a) **Calculate** the average speed for each of the sections A, B and C.
   b) **Describe** the motion of the object in the graph.

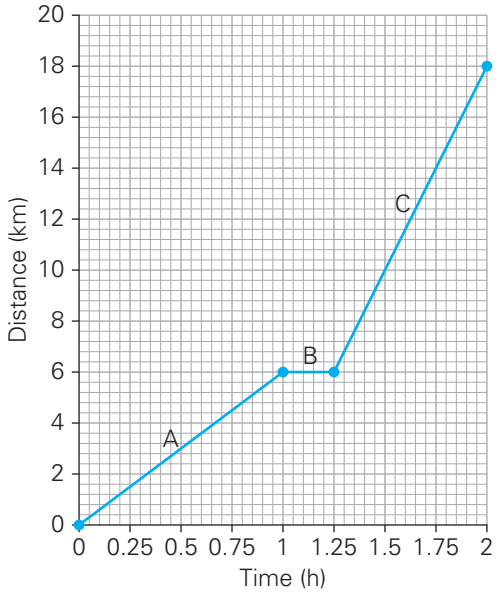

Figure 7.19 Distance–time graph of a moving object

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Displacement–time graphs

Displacement–time graphs display an object's movement with respect to a starting point. The starting position is always located on the graph at the coordinate (0, 0), and is referred to as the **origin**. When displacement returns to 0 on the y-axis, the object has returned to the point of origin at a particular time. This type of graph shows an object's displacement as it travels away from and towards the origin over time. The gradient of a displacement–time graph is the average velocity as it includes information of direction.

origin
the 0 point on the *y*-axis of a displacement–time graph

$$v_{av} = \frac{s}{t} = \frac{\text{rise}}{\text{run}}$$

Worked example 7.6

Displacement–time graph

Remember the distance–time graph for Elliott's walk. Here is his displacement–time graph for the same motion.

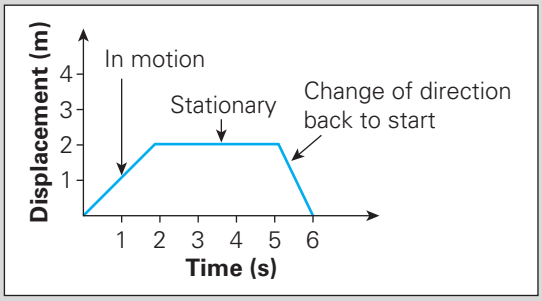

Figure 7.20 Displacement–time graph of Elliott's walk

1. Describe his movements in relation to his starting point.
2. Calculate his velocity at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

Working	Explanation
1. Describing movements	
For the first 2 seconds, Elliott moves away from his starting position by 2 metres. For the next 3 seconds, he is stationary. In the final second, he increases his velocity moving back to the origin (his starting position).	The displacement *y*-axis indicates how far from the start he is. In the distance–time graph, you could not tell in which direction he was travelling, only that he was moving.
2. Average velocity	
0 to 2 seconds: $v_{av} = \frac{\text{rise}}{\text{run}} = \frac{(2-0)\text{ m}}{(2-0)\text{ s}} = \frac{2\text{ m}}{2\text{ s}} = 1\text{ m s}^{-1}$ 2 to 5 seconds: A horizontal line indicates that he is stationary. In other words, $v = 0\text{ m s}^{-1}$. 5 to 6 seconds: $v_{av} = \frac{\text{rise}}{\text{run}} = \frac{(2-4)\text{ m}}{(2-6)\text{ s}} = \frac{-2\text{ m}}{1\text{ s}} = -2\text{ m s}^{-1}$	Select two points from each interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the average velocity. A negative velocity means that he has changed directions and is travelling in the opposite direction – in this case, back to the start. He is travelling faster towards his original position (5 to 6 seconds) than he was when travelling away from it (0 to 2 seconds).

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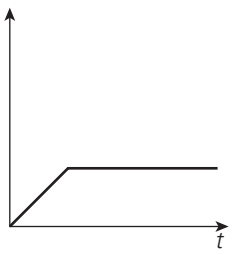
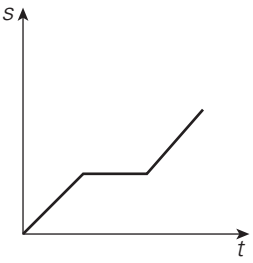
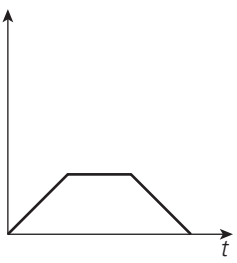
Quick check 7.6

1. **Describe** the motion of an object according to the following displacement–time graph shapes.

a) 

b) 

c) 

Making thinking visible 7.2

Elaboration game: Displacement–time graphs

As a group of four, observe the displacement–time graph in Figure 7.21.

1. One person starts a plausible story by describing the first motion in the graph.
2. When the motion changes, a second person in the group continues the plausible story until the motion changes again.
3. Continue to take turns creating the motion story until each group member has had two turns.
4. Bring together your creative story that accurately describes what is occurring in the displacement–time graph.

Hold off on giving your ideas unless it is your turn to continue the story. Remember to include words from this chapter such as 'constant velocity', 'stationary', 'acceleration' and 'at rest'. Be creative!

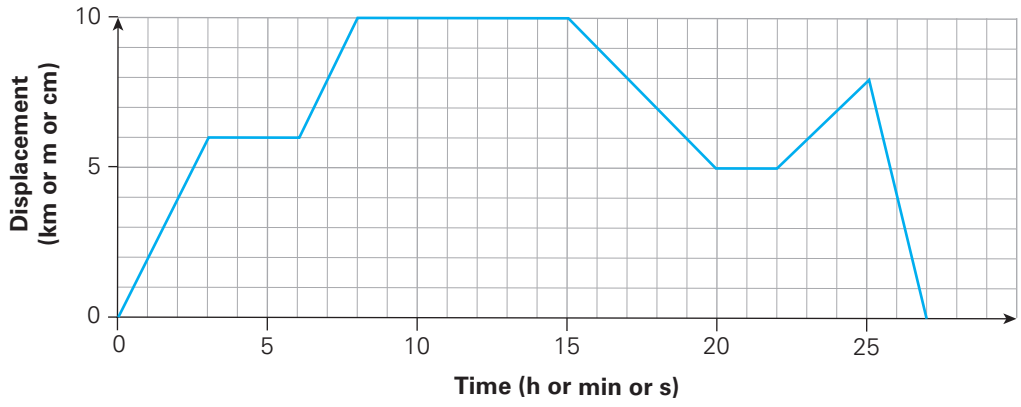


Figure 7.21 Displacement–time graph

Challenge: If you have finished your story, calculate the velocity at certain points along the path.

The *Elaboration game* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Velocity–time graphs

WORKSHEET
Speed–time and velocity–time graphs

Velocity–time graphs show the velocity of an object over time. This is a very versatile graph as it can be used to calculate other quantities such as displacement, instantaneous velocity and acceleration:

- Instantaneous velocity can be read directly from the line at any point in time.
- The gradient between two points on a velocity–time graph represents the acceleration over that time period.

$$a = \frac{v - u}{t} = \frac{\text{rise}}{\text{run}}$$

- The area under a velocity–time graph is the displacement of an object in that time period.

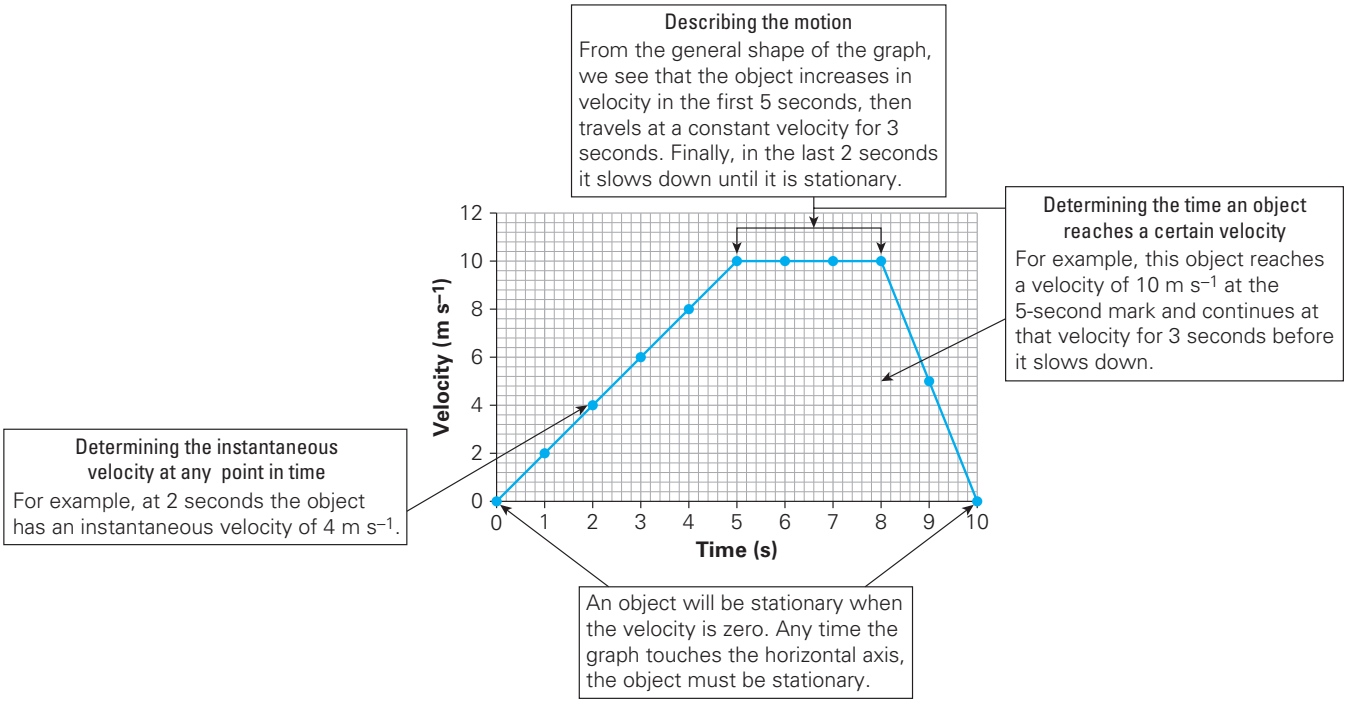
Describing the motion
From the general shape of the graph, we see that the object increases in velocity in the first 5 seconds, then travels at a constant velocity for 3 seconds. Finally, in the last 2 seconds it slows down until it is stationary.
Determining the time an object reaches a certain velocity
For example, this object reaches a velocity of 10 m s−1 at the 5-second mark and continues at that velocity for 3 seconds before it slows down.
Determining the instantaneous velocity at any point in time
For example, at 2 seconds the object has an instantaneous velocity of 4 m s−1.
Velocity (m s−1)
Time (s)
0
2
4
6
8
10
12
0
1
2
3
4
5
6
7
8
9
10
An object will be stationary when the velocity is zero. Any time the graph touches the horizontal axis, the object must be stationary.

Figure 7.22 A velocity–time graph tells you a lot about an object's motion.

Reading instantaneous velocity

Imagine that a detector is used to capture the instantaneous velocity of an object moving in a straight line away from the detector. It records at every second for a period of 10 seconds, and the following table is created. The data within it can then be represented on a velocity–time graph.

Velocity (m s^{-1})	0	2	4	6	8	10	10	10	10	5	0
Time (s)	0	1	2	3	4	5	6	7	8	9	10

Figure 7.23 What sort of graph shape would a car speeding up to get onto the freeway look like?

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Finding acceleration from the gradient

The three velocity–time graphs in Table 7.2 help to identify when an object in motion is accelerating, decelerating or travelling at a constant velocity.

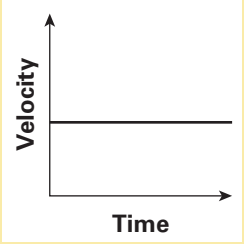
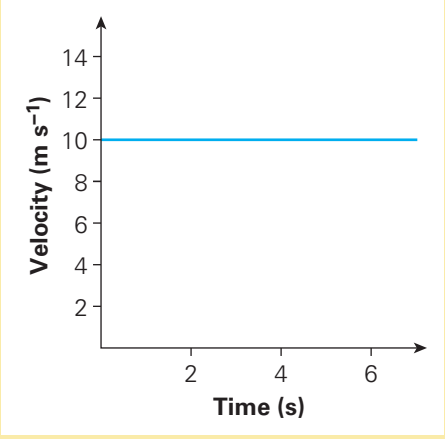
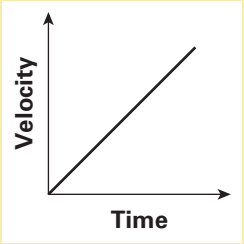
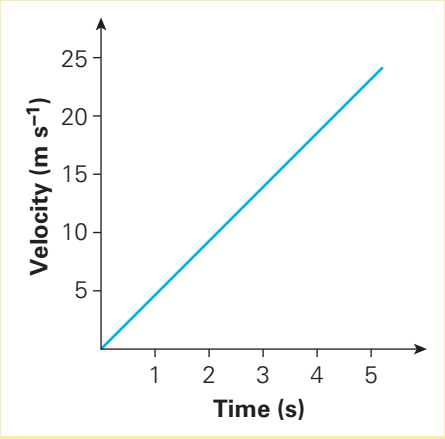
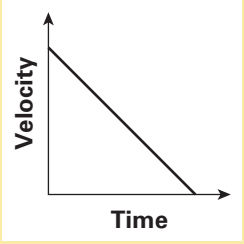
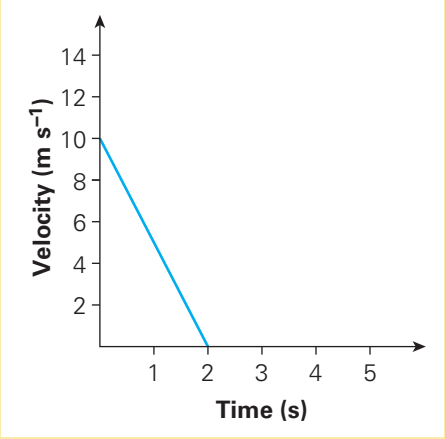
Shape	Explanation	Example
	A horizontal line indicates that an object is travelling at a constant velocity.	 $a = \frac{\text{rise}}{\text{run}} = \frac{0\text{ m s}^{-1}}{10\text{ s}} = 0\text{ m s}^{-2}$
	A positive gradient means positive acceleration (speeding up). The steeper the gradient, the more the object accelerates.	 $a = \frac{\text{rise}}{\text{run}} = \frac{25\text{ m s}^{-1}}{5\text{ s}} = 5\text{ m s}^{-2}$
	A negative gradient means negative acceleration (deceleration). The steeper the gradient, the quicker the object decelerates.	 $a = \frac{\text{rise}}{\text{run}} = \frac{-10\text{ m s}^{-1}}{2\text{ s}} = -5\text{ m s}^{-2}$

Table 7.2 Three types of velocity–time graphs

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Calculating displacement

Displacement can be calculated from a velocity–time graph by calculating the area under the graph. In some cases, it is easier to split the graph into smaller sections.

Worked example 7.7

Calculating the displacement

Consider the graph in Figure 7.24 of an object in motion.

1. Calculate the displacement in the first 5 seconds.
2. Calculate the displacement from $t = 5$ to $t = 8$.
3. Calculate the displacement in the final 2 seconds.
4. Determine the total displacement covered by the object over the entire 10 seconds.

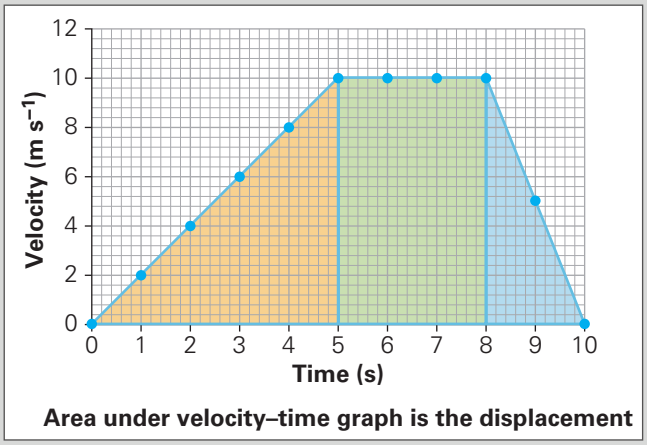
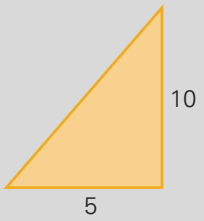
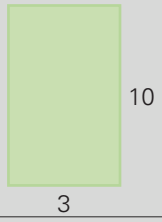


Figure 7.24 Velocity–time graph

Working	Explanation
1. Displacement in the first 5 seconds	
The area in the first 5 seconds can be described by the triangle shown. $A_1 = \frac{1}{2}(5)(10) = 25$ This means that in the first 5 seconds the object displaces 25 metres. 	Redraw the shape and label the known sides. Calculate the area of the triangle, which is given by the formula $A_1 = \frac{1}{2}bh$. Interpret the area, and check that units are correct.
2. Displacement from $t = 5$ to $t = 8$	
The area under the graph between $t = 5$ and $t = 8$ can be described by the rectangle shown. $A_2 = 3 \times 10 = 30$ This means that the displacement over this period is 30 metres. 	Redraw the shape and label the known sides. Calculate the area of the rectangle, which is given by the formula $A_2 = l \times w$. Interpret the solution with correct units.
3. Displacement in the final 2 seconds	
The area under the graph in the final 2 seconds is represented by the triangle shown. $A_3 = \frac{1}{2}(2)(10) = 10$ In the final 2 seconds the object displaces 10 metres. 	Redraw and label the shape. Calculate the area. Interpret solution with correct units.
4. Total displacement	
Sum the areas to obtain the total distance covered. $A_T = A_1 + A_2 + A_3$ $= 25 + 30 + 10$ $= 65$ Therefore, the total displacement by the object over the 10 seconds is 65 metres.	Add up all of the area sections under the graph to get the total displacement.

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Try this 7.3

Plotting the motion of students over 100 metres

Instructions

1. Copy the results tables into your science book.
2. As a class, choose two students to run a 100-metre sprint.
3. All other students should line up at the 0-, 20-, 40-, 60-, 80- and 100-metre marks with a stopwatch.
4. Use stopwatches to capture the time from when a sprinter begins to when they pass each 20-metre mark. Ideally, there will be at least two classmates at each point so that an average of the times can be calculated. Record these results in the table.

Results

1. Calculate the difference in elapsed time for each 20-metre interval.

Sprint times (s) at each 20 m mark					
Student name	**20 m**	**40 m**	**60 m**	**80 m**	**100 m**

2. Calculate the average velocity for each interval and complete the table of average velocity for each distance.

Average velocity (m s^{-1})					
Student name	**0–20 m**	**20–40 m**	**40–60 m**	**60–80 m**	**80–100 m**

3. Plot the displacement–time graph by drawing smooth trend lines.

Discussion

1. Describe the shapes of each interval in each graph.
2. Propose why it was important to gather data from more than one classmate.
3. Identify some potential sources of error in the data.

WORKSHEET Distance–time, speed–time and acceleration–time graphs

Quick check 7.7

Analyse the velocity–time graph in Figure 7.25.

1. **Describe** the motion of the object shown in the graph.
2. **Calculate** the acceleration over the first two seconds.
3. **Calculate** the acceleration between $t = 2$ and $t = 4$.
4. **Calculate** the displacement after the first two seconds.
5. **Determine** the total displacement over four seconds.

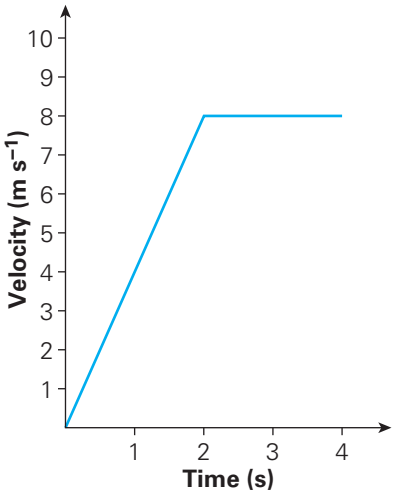

Figure 7.25 Velocity–time graph

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Section 7.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 7.2 questions

Remembering

1. **Recall** what the gradient of a displacement–time graph indicates.
2. **Recall** what the gradient of a velocity–time graph indicates.
3. **Recall** what the area under a velocity–time graph indicates.

Understanding

4. Consider the velocity–time graph in Figure 7.26.
   a) **Calculate** the acceleration in the first three seconds.
   b) **Calculate** the acceleration for the next two seconds.
   c) **Calculate** the displacement of the object after five seconds.

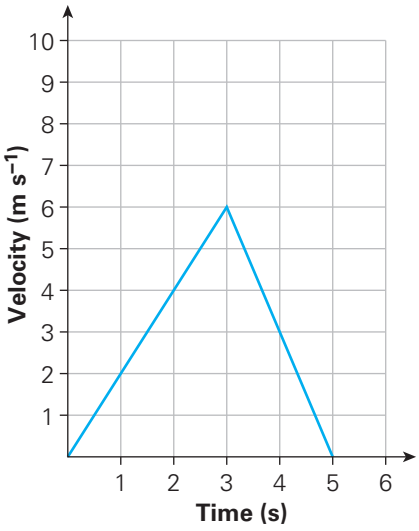

Figure 7.26 Velocity–time graph

Applying

5. **Describe** what the shape of a displacement–time graph can reveal about an object's movements.
6. **Describe** what the shape of a velocity–time graph can reveal about an object's movements.
7. The path of a hiker in the Kalbarri National Park from a car park to a lookout is described in the displacement–time graph in Figure 7.27.
   a) **Calculate** the hiker's displacement to the lookout, where they sat to take a break.
   b) **Calculate** the average velocity of the hiker in the first two hours.
   c) **Calculate** for how long the hiker sits at the lookout.
   d) **Calculate** the velocity of the hiker on their way back to the car park.

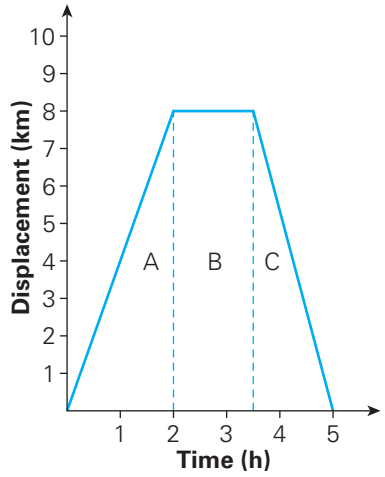

Figure 7.27 Displacement–time graph of a hiker's walk

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Analysing

8. Hundreds of thousands of animals in Australia are killed every year by vehicles. Consider the velocity–time graph in Figure 7.28.

a) If a driver travelling at 90 km h^{-1} takes 0.5 seconds to react, and they come to a stop according to the following velocity–time graph, **calculate** the total stopping displacement.

b) If the reaction time was increased to one second, **calculate** what the stopping displacement would be.

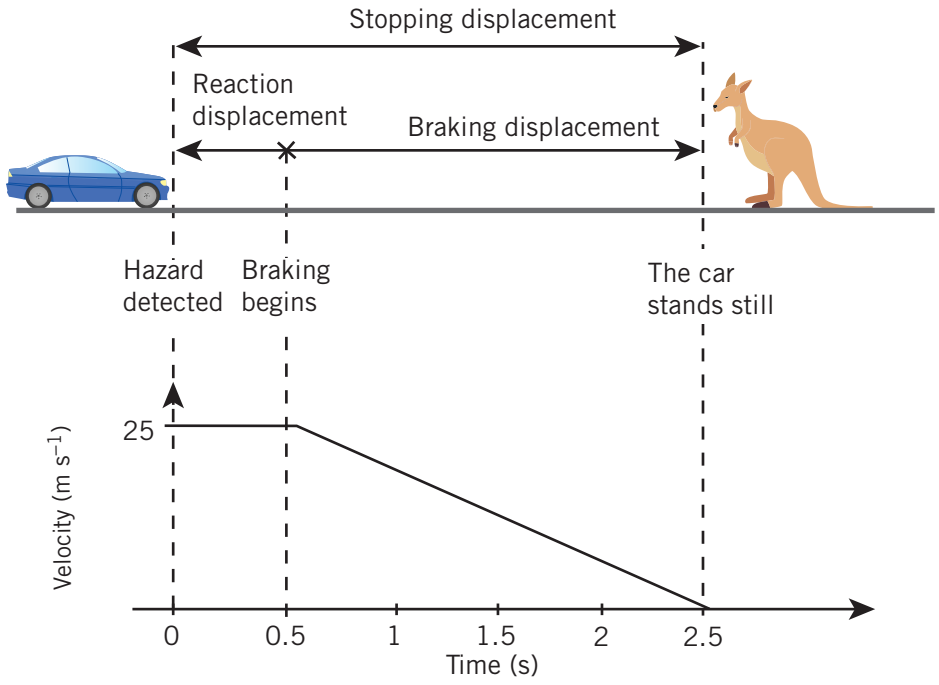

Figure 7.28 Velocity–time graph

Evaluating

9. **a)** Use the following table to **construct** a displacement–time graph of a koala.

Time (s)	Displacement (m)
0	0
2	2
5	3
7	3
9	4
10	5

b) Using the graph, **propose** what conclusions can be made about the koala's movements, including whether we can tell the direction in which it went.

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7.3 Newton's laws of motion

Learning goals

At the end of this section, I will be able to:

1. Recall Newton's first law of motion.
2. Use the equation $F = ma$, Newton's second law of motion.
3. Recall Newton's third law of motion.
4. Investigate how Aboriginal and Torres Strait Islander Peoples used tools to increase impact force.
5. Apply Newton's laws of motion in sports and transportation.

WORKSHEET
Forces and Newton's laws of motion

VIDEO
Newton's first law

Sir Isaac Newton's three laws of motion

Newton's first law of motion

Newton's first law of motion is the law of **inertia**.

NEWTON'S FIRST LAW

An object will remain at rest or travel at a constant speed in a straight line unless it is acted upon by an external force.

Newton's first law of motion
an object will remain at rest or moving at a constant speed in a straight line unless acted upon by an external force

inertia
the tendency of an object to remain in its state of motion in the same direction unless acted upon by an external force

force
any interaction that, when unopposed, will change the motion of an object

net force
the sum of all the forces acting on an object

A **force** is a push or a pull, and when unopposed, a net force causes an object to speed up, slow down or change direction. Force describes a magnitude and a direction and is a vector quantity. In the real world, an object will often have multiple forces acting on it, all contributing to that object's motion.

If the multiple forces acting on an object are balanced – the forces are equal in magnitude and occurring in opposite directions – the object's motion will not change. A stationary object will remain stationary, and a moving object will continue to move in the same direction at constant velocity. The term **net force** is used to describe the sum of all forces acting on an object.

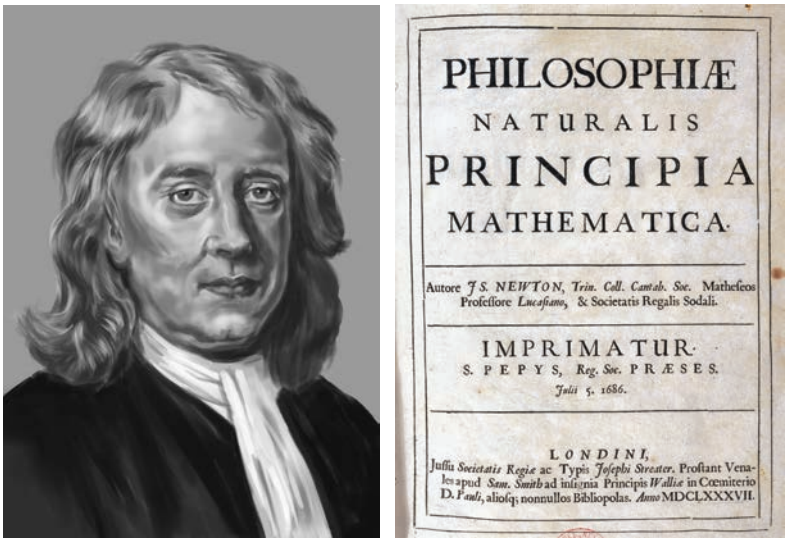
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA
Autore J.S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.
IMPRIMATUR
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.
LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostant Venales apud Sam. Smith ad insignia Principis Walliæ in Cœmiterio D. Pauli, aliosq; nonnullos Bibliopolas. Anno MDCLXXXVII.

Figure 7.29 Newton's *Philosophiae Naturalis Principia Mathematica* (The Mathematical Principles of Natural Philosophy) was published in 1687. It revolutionised the scientific thinking of the time by formulating the laws of motion.

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When the net force is zero ($F_{net} = 0$), the forces are balanced and will not change the motion of the object. However, if the forces applied to an object are unbalanced ($F_{net} \neq 0$), the object will either accelerate, decelerate or change direction.

Inertia is responsible for the feeling that you get when you suddenly change motion in a car, train or aeroplane or on a bike. At times, when we travel at a constant speed, we hardly even recognise that we are moving. But when the vehicle that we are travelling in suddenly stops, turns a sharp corner or accelerates, we notice that our body moves unexpectedly. This is inertia! It is the tendency of objects to either stay at rest or continue travelling at a constant speed, in the same direction.

$F_{net} = 0$	$F_{net} \neq 0$
The forces acting on an object are balanced and sum to zero. The object's speed and direction do not change.	The forces on the object are unbalanced and sum to either a positive or negative number. The motion of the object changes. It either speeds up or slows down or changes direction, depending on the direction of the net force.

Table 7.3 The effect of balanced and unbalanced forces

Figure 7.30 Consider travelling in a car at a constant speed. When the brakes are suddenly pressed, the car quickly slows down but our body continues to move forwards at the original speed. If it were not for seatbelts, we would continue our motion through the front window of the car.

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Try this 7.4

Inertia at a roundabout

Imagine you are sitting in the back seat of a car and the driver drives around a roundabout rather quickly. How does your body move? You might have experienced a force pulling you to the side. Remembering that inertia is an object's tendency to resist a change in motion, consider how your body moves in a car when it:

- travels at a constant speed
- brakes suddenly
- takes a roundabout turn quickly
- takes off at a green light.

Figure 7.31 You can feel the effect of inertia when you're going around a roundabout.

Newton's second law of motion

Newton's second law of motion is a mathematical formula that describes the relationship between net force, **mass** and acceleration.

Newton's second law of motion
an object acted upon by a force experiences acceleration in the same direction proportional to the magnitude of the net force and inversely proportional to the mass of the object

mass
the quantity of matter

NEWTON'S SECOND LAW

The net force acting on an object equals the mass of the object multiplied by its acceleration.

It can also be written as:

$$\text{net force (N)} = \text{mass (kg)} \times \text{acceleration (m s}^{-2}\text{)}$$
$$F_{net} = ma$$

NOTE: The units for force are newtons, N, in which 1 N is equal to 1 kg m s^{-2}.

From this equation, the following relationships can be noted:

- The greater the mass of the object, the greater the force needed to accelerate it.
- The greater the force applied to an object, the greater its acceleration.
- If an object is accelerating, then there must be a net force.

Figure 7.32 shows a cricket bat hitting a cricket ball with a mass of m. When a net force, F_{net}, is applied to the cricket ball, it will experience an acceleration, a. If a cricket ball with a larger mass of $2m$ was hit with the same net force, F_{net}, its acceleration ($1/2a$) will be less than that of the original ball. Finally, if the cricket ball is hit harder with a net force of $2F_{net}$, its acceleration will also increase to $2a$, in proportion to the force.

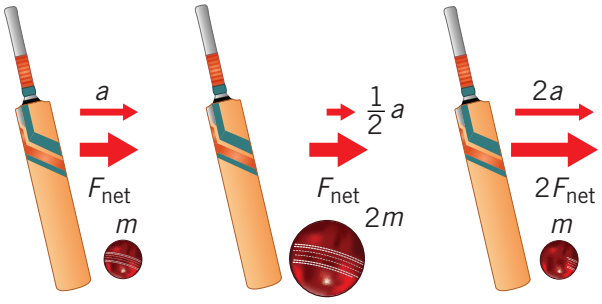

Figure 7.32 A cricket ball hit by a bat follows Newton's second law of motion.

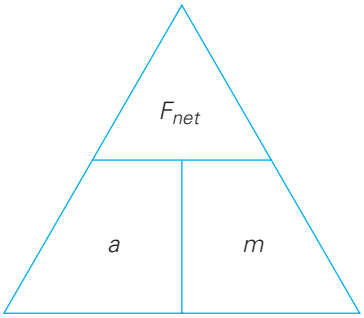

Figure 7.33 To use the force triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

VIDEO
Newton's second law

WIDGET
Newton's second law

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Using the force triangle (see Figure 7.33), we have:

$$F_{net} = ma, \qquad a = \frac{F_{net}}{m}, \qquad m = \frac{F_{net}}{a}$$

Newton's first law of motion describes how a net force on an object is required to overcome its inertia and change its motion. Newton's second law of motion allows this change in motion to be quantified.

Worked example 7.8

Consider two students moving a table of mass 13 kilograms. One student pushes horizontally with a force of 30 N while the other pulls horizontally with a force of 80 N. Ignore all vertical forces and ignore frictional forces between the table and the floor.

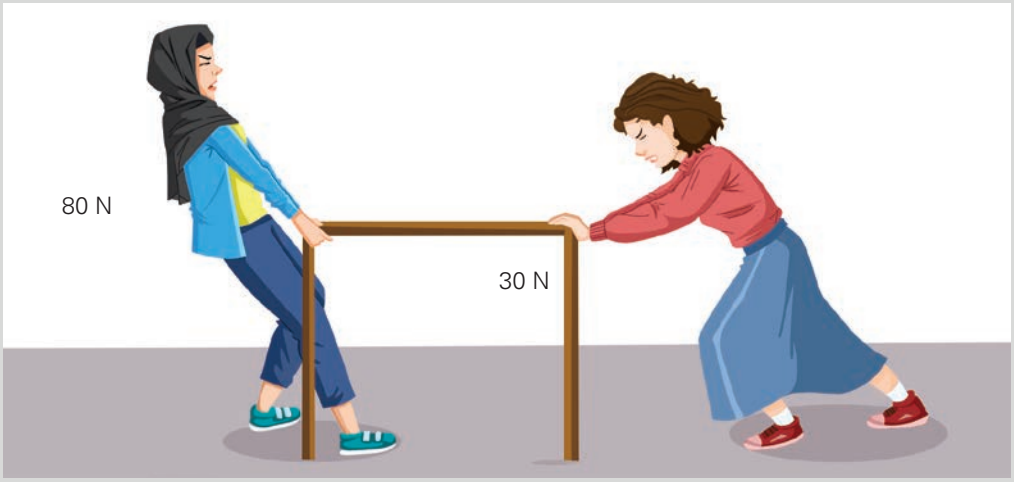

Figure 7.34 Two students trying to move a table

1. Determine the net force and direction of the table.
2. Calculate the acceleration of the table.

Working	Explanation
1. Net force	
F_{net} = 30 + 80 = 110 N to the left There is effectively 110 N of force acting on the table towards the left.	Calculate the net force by adding all of the forces acting on the object, i.e. the table. Since the surface of the floor pushes up on the table with the same force as the table pushes back on the floor, you can ignore the vertical forces. The only relevant forces acting on the table are the two in the horizontal direction. The net force is the sum of the two forces that the students exert on the table.
2. Acceleration	
$a = \frac{F_{net}}{m}$ $a = \frac{110\text{ N}}{13\text{ kg}} = 8.46\text{ m s}^{-2}$ to the left	Newton's second law allows you to calculate how quickly the table will accelerate if you know what the mass of the table is. (In real life there would be a frictional force between the table and the floor acting against the motion. If, in this example, the frictional force was 50 N, then the net force would be 110 N – 50 N = 60 N and the acceleration would be 60 N/13 kg = 4.62 m s^{-2} to the left.)

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Newton's discovery of gravity

gravity the force by which a planet or other body draws objects towards its centre

weight the force of gravity on the mass of an object

The story goes that an apple falling from a tree onto Newton's head led him to wonder why the Moon does not also fall towards Earth. His question led him to the discovery of **gravity**, which is an attractive non-contact force felt by all objects that have a mass. The greater the mass of an object, such as a planet, the greater the gravitational force it will exert. This discovery answered Newton's question about the Moon: he was able to identify that the Moon is attracted to Earth's gravity, just as the apple is, but the Moon's attraction and speed causes it to orbit Earth.

Mass is the quantity of matter in an object and does not change regardless of the gravitational force acting on it. Mass is measured in kilograms when using SI units. **Weight** is different to mass, as it is actually a force, measured in newtons. In physics, weight is often called the 'force due to gravity', or the 'weight force'. It is calculated by multiplying the mass of the object by the acceleration due to gravity acting on it. For example, Earth's gravitational field pulls objects to its centre at a rate of 9.8 m s^{-2}, so a person with a mass of 70 kilograms will have a weight of 70 kg × 9.8 m s^{-2} = 686 N.

In general, you can use the following equation to calculate the weight force:

$$F_{weight} = mg$$

where F_{weight} is the force due to gravity, also known as the weight force measured in newtons (N), m is the mass of the object measured in kilograms, and g is the strength of the gravitational field measured in m s^{-2}. Note that g can be given as 9.8 m s^{-2} or 9.8 N kg^{-1}; the two units are equivalent. The unit N kg^{-1} is convenient when working out the weight of an object.

Remember that the mass of an object is the same regardless of the strength of the gravitational field.

Earth	Moon	Mars	Venus
g = 9.8 N kg^{-1}	g = 1.6 N kg^{-1}	g = 3.7 N kg^{-1}	g = 8.9 N kg^{-1}

Table 7.4 The strength of the gravitational field is different on Earth, the Moon, Mars and Venus.

Quick check 7.8

1. **Calculate** the force that is required to accelerate an object with a mass of 6 kilograms at 2.3 m s^{-2}.
2. **Calculate** the mass of an object that accelerates at 0.2 m s^{-2} when it is pushed with a force of 20 N.
3. If a car with a mass of 1000 kilograms is travelling at a constant velocity, **calculate** the deceleration when the brakes are applied with a force of 1500 N.
4. **Calculate** the weight of a 60 kg person on Earth, the Moon, Mars and Venus.

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Practical 7.2 Self-design

Acceleration due to gravity

Aim

To accurately calculate acceleration due to gravity.

Useful equation

$$\text{Acceleration due to gravity (m s}^{-2}) = \frac{2 \times \text{distance travelled during vertical descent (m)}}{\text{time}^2\ (\text{s}^2)}$$

Materials

- a number of objects to drop (e.g. marble, steel ball bearing, tennis ball)
- 3-metre measuring tape
- smartphone with high-speed slow-motion capabilities

Method

Use the formula given as a guide to design a method of accurately calculating acceleration due to gravity.
For example, tape the 3-metre measuring tape to a wall and drop different objects a number of times. Try a few different dropping heights. Analyse the high-speed videos.

Results

1. Create a table for your results.
2. Record all the collected data.
3. Process the data to produce an estimate of the magnitude of the acceleration due to gravity.

Discussion

1. Discuss if the different objects accelerate at the same rate. Why or why not?
2. State how many trials there were of the same object and why that number was selected.
3. Determine if air resistance affected your results. Explain your reasoning.
4. Explain why you did not measure the mass of the various objects that you were dropping.
5. Compare your results with the accepted value of the magnitude of the acceleration due to gravity.

Explore! 7.2

Protecting drivers and passengers

Car crashes can result in extreme forces acting on humans within the crashed vehicle. Engineers are constantly investigating ways to reduce the possible impact forces on drivers and passengers of all body types and ages. They might do this by conducting test car crashes with human-like crash-test dummies or even by engineering driverless cars, whose reaction times are far superior to those of humans, to reduce the occurrence of crashes.

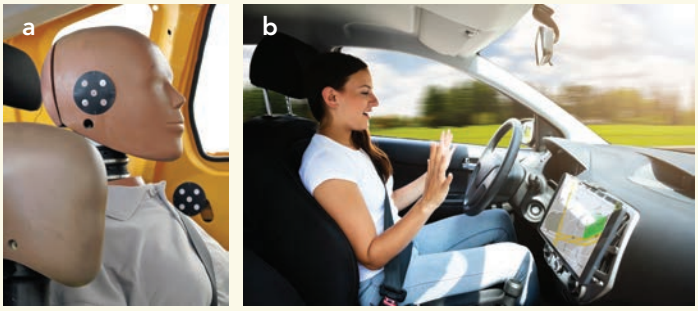

Figure 7.35 (a) Female and child crash-test dummies in a car; **(b)** a woman sitting in a driverless car

Use the internet to research the answers to the following questions.

1. In 2022, the first female crash-test dummy was produced. Why was this important for the future of car safety?
2. What are some causes of car crashes, even if the driver is following the road rules?
3. Driverless cars will have a 360-degree view of their surroundings, and a faster reaction time and better braking performance than a human driver. Research your preferred car brand and describe the timeframe for the future of any driverless vehicles in production.

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Practical 7.3 Self-design

Force and mass

Aim

To investigate the effects of force or mass on acceleration.

Hypothesis

Write a hypothesis regarding the effect of changing force or mass on the velocity or acceleration of a trolley.

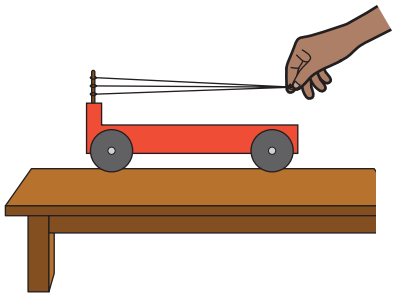
Materials

- crash trolley
- elastic bands
- weights
- tape
- stopwatch
- data logger (if available)

Method

1. Design an experiment that investigates the effects of either force or mass on acceleration.
2. Team up with another group, who should investigate the effect of the other factor (force or mass).

NOTE: You can use increasing numbers of elastic bands to demonstrate increased force applied on the trolley, and increased masses on the trolley to investigate mass.



Results

1. Record your mass, force, velocity or acceleration data in an appropriate table.
2. Plot an appropriate graph or graphs of force or mass versus velocity and/or acceleration.

Discussion

1. As force increases, what happens to velocity and acceleration?
2. As mass increases, what happens to velocity and acceleration?
3. How can your experimental design be improved?
4. Identify any sources of error (experimental uncertainty or experimental faults).

Conclusion

1. Make a claim about force, mass, velocity and acceleration based on this experiment.
2. Support your statement by referring to your experimental data.
3. State whether your hypothesis was supported or not.

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Newton's third law of motion

Newton's third law of motion
for every action, there is an equal and opposite reaction

Newton's third law of motion describes that a force exerted by an object on another object will also have a reactive force exerting back in the opposite direction. These are called action and reaction forces. For example, if you were to push on a wall, the wall pushes back just as hard (see Figure 7.36) – if it did not, you would fall through!

NEWTON'S THIRD LAW

For every action, there is an equal and opposite reaction.

Action and reaction pairs always act on different objects exerting a force. For example, when you walk on the ground, you exert a force on the ground, but you don't fall through the ground as an equal and opposite force is acting back on you. Similarly, if you were to exert a force to throw a ball, the ball would also exert a force back onto your hand. For every action force, there is a reaction force.

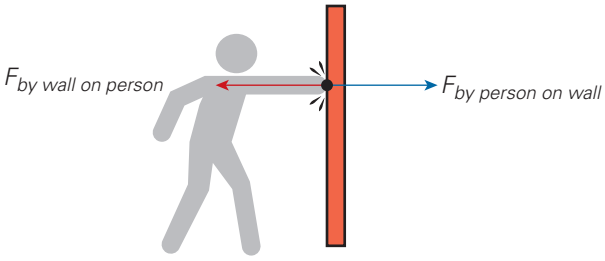

Figure 7.36 The action of pushing against a wall has a reaction force that pushes back on the person with the same magnitude.

Force of trampoline on girl
Force of girl on trampoline
Force of girl on Earth (due to gravity)
Force of Earth on girl (due to gravity)

Figure 7.37 As a person lands on a trampoline, they exert a force downwards on the mat when in contact with it. The mat then pushes them back up with an equal but opposite force. This causes the person to slow down and stop, then bounce back into the air.

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Explore! 7.3

eRideables

In Western Australia, helmets are compulsory when riding bicycles and eRideables such as electric bikes and electric scooters. Helmets are capable of reducing the impact force of the head on another hard object such as the ground in a crash or fall. They also increase the visibility of riders, potentially reducing the risk of collisions on footpaths or roads.

Figure 7.38 Riding an electric scooter requires a helmet in Western Australia.

Use the internet to investigate the statistic that helmets can reduce the risk of head and brain injury for e-scooter riders by at least 80%. Examine the information that you collect in your research and make a statement on the effectiveness of helmets in enhancing the safety of e-scooter riders.

Try this 7.5

Newton's third law in sport

Action and reaction forces are at play in all sports, and some of those forces can impact the safety of players. Consider some of the safety gear or precautions in the rules of the following sports that might protect players from dangerous action and reaction forces.

Figure 7.39 Jordan Mailata, an Australian professional American football player, wears protective gear when playing for the Philadelphia Eagles.

Sport	Protective gear or rules
Rugby	
Australian rules football	
Netball	
Cricket	
Horse riding	
American football	
Ice hockey	

Table 7.5 Action and reaction forces

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Explore! 7.4

Projectiles and throwing devices

Aboriginal and Torres Strait Islander Peoples have developed and refined the use of spears, spear throwers, and bows and arrows over tens of thousands of years, demonstrating advanced knowledge of physics, engineering and environmental adaptation. These tools vary widely across different regions of Australia, reflecting the diverse cultural practices and environmental conditions of each community.

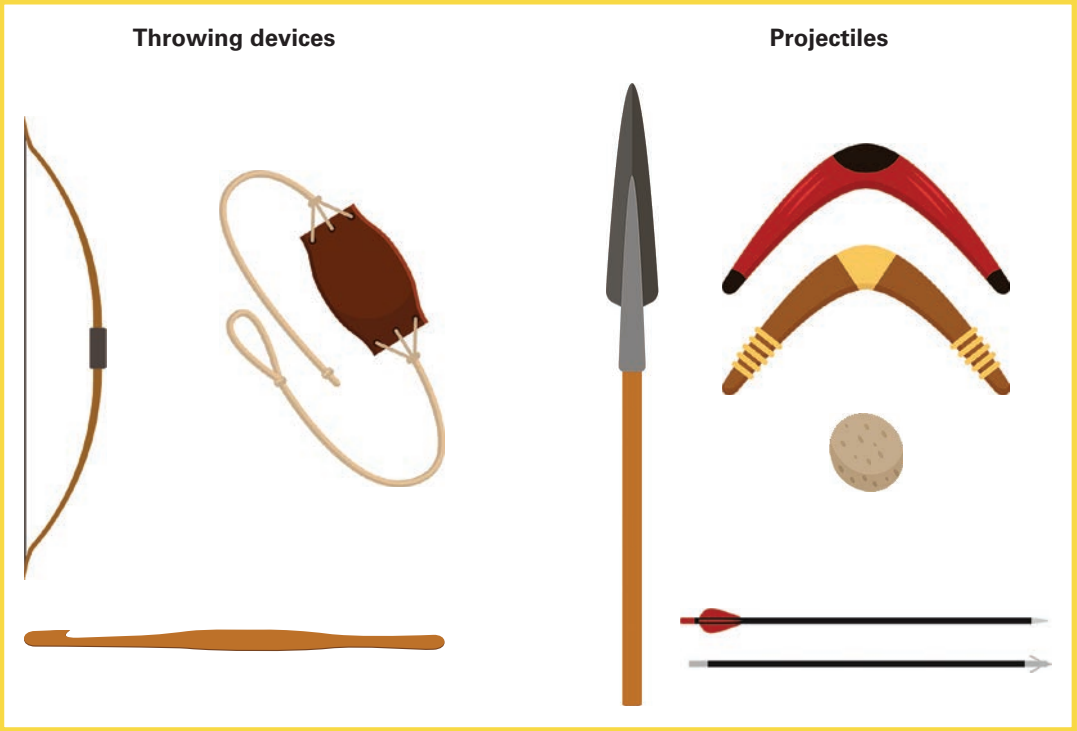

Figure 7.40 What type of throwing device is a boomerang?

Spear throwers, known as woomeras in some regions, and bows function as mechanical advantage devices, amplifying the force applied to the projectile. By increasing the leverage and acceleration, these tools enable greater velocity, range and impact force. This innovation showcases a deep understanding of the relationships between mass, force and motion, as well as practical knowledge gained through generations of observation and experimentation.

For example, spear throwers are often tailored to the size and weight of the spear to optimise performance, and their design incorporates features that allow for precise targeting and energy transfer.

Use your preferred search engine to research the principles behind these tools and explore how Aboriginal and Torres Strait Islander Peoples have used them to adapt to different environments. Consider how these technologies reflect their innovation, cultural significance and sustainable practices.

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Practical 7.4 Self-design

Crash-test eggs

Aim

To design and build a car with safety features that will protect an egg from breaking during a collision.

Hypothesis

Write a hypothesis investigating how the crash impact force and speed will affect whether the egg in the car will break.

Materials

As chosen by students but may include:

- rubber bands
- wheels
- icy-pole craft sticks
- dowels
- plastic cups
- straws
- rubber bands
- string
- springs
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- plastic bottles
- flat cardboard
- sticky tape

Method

1. Research vehicle collisions, safety features of cars and the forces involved during a collision.
2. Based on your research, design and build a vehicle or device that has safety features to protect an egg during a collision.
3. Test your design by competing as a class to see whose crash-test egg survives.

Results

Take a high-speed video of your collision and slow it down to see the forces in effect.

Discussion

1. Compare your safety device to a safety feature in a car.
2. Draw the forces acting on the egg during the collision.
3. Describe how seatbelts, airbags and crumple zones in a car reduce the force on a passenger in a car crash. How have you modelled these aspects in your model?
4. What difficulties or errors did you encounter during this experiment? How could you improve the experiment to avoid these in the future?

Conclusion

1. Make a claim about safety based on this activity.
2. Support the statement by using your observations and include potential sources of error.
3. State whether your hypothesis was supported or not.

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Section 7.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 7.3 questions

Remembering

1. An object is travelling at a constant speed and zero net force is applied to it.
   a) **Recall** what happens to the object.
   b) **Identify** which of Newton's laws of motion applies in this situation.

Understanding

2. **Calculate** the mass of an object, to two decimal places, that accelerates at 0.63 m s^{-2} when it is pushed with a force of 20 N.
3. If a car with a mass of 1500 kilograms is travelling at a constant velocity, **calculate** the deceleration when the brakes are applied with a force of 1200 N.

Figure 7.41 A 1500 kg car driving at constant velocity

Applying

4. **Define** the term 'inertia'.
5. **Describe** the term 'net force'.
6. **Describe** the term 'weight'.

Analysing

7. **Contrast** the quantities 'weight' and 'mass'.

Evaluating

8. A 50-kilogram person sits on a chair with their feet dangling above the ground. **Construct** a diagram to represent the action–reaction pair of forces acting in the scenario and include labels to indicate the force quantities. (Note that acceleration due to gravity, g, is equal to 9.8 m s^{-2}.)
9. Two students are trying to push a mass towards each other. Student 1 on the left exerts a force of 155 N on the mass to the right, and student 2 on the right exerts a force of 220 N to the left. Ignore frictional forces.
   a) **Calculate** the net force acting on the mass.
   b) **Deduce** the direction in which the mass will move.
   c) Using Newton's second law, if the mass is 216 kilograms, **calculate** the acceleration of the mass.
   d) **Suggest** whether there are action–reaction pairs in the system. Quantify the forces where possible.

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Chapter review

Chapter checklist

Success criteria		Linked questions
7.1	I can distinguish between scalar and vector quantities.	2
7.1	I can calculate the speed of an object in units of m s^{-1} and km h^{-1}.	8, 10a
7.1	I can describe and distinguish between distance, displacement, speed and velocity.	1, 4
7.1	I can calculate the acceleration of an object.	10b
7.2	I can use velocity–time, distance–time and displacement–time graphs to analyse and communicate an object's motion.	9, 10c
7.3	I can explain Newton's three laws of motion.	3, 5
7.3	I can explain how knowledge of Newton's laws of motion can be applied, e.g. in sports, safety or transport issues.	6
7.3	I can describe how Aboriginal and Torres Strait Islander people achieve an increased impact force through the use of spear-throwers and bows.	7

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review

Review questions

Remembering

1. **Distinguish** between distance and displacement, and between speed and velocity, using an example.
2. **Recall** the difference between scalar and vector quantities, and state one example of each.
3. **Describe** Newton's three laws of motion.

Understanding

4. **State** one example that demonstrates average speed and one example that demonstrates instantaneous speed.
5. **Identify** three action–reaction pairs in Figure 7.42.
6. **Describe**, using your knowledge of Newton's third law of motion, how a cricket helmet can protect a player's head from the impact force of a cricket ball.
7. Use of a spear-thrower increases a spear's speed. **Describe**, using your knowledge of Newton's second law of motion, how the use of an Aboriginal or Torres Strait Islander spear-thrower can increase the impact force of a spear.

Figure 7.42 Action–reaction pairs acting on AFL players

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Applying

8. Consider the hypothetical times of Cathy Freeman's personal best 400-metre sprint.

Distance (m)	0	50	100	200	300	400
Time (s)	0	5.98	11.54	23.65	35.22	48.63

a) **Calculate** the average speed of Cathy Freeman for the entire 400 metres – that is, from $t = 0$ to $t = 48.63$.

b) **Determine** if she travels quicker in the first 200 metres or the last 200 metres.

Analysing

9. Consider the path of a bungee jumper. For simplicity, assume that the path of motion is straight up and down. As a person jumps from the platform, they accelerate towards the ground. They decelerate when the rope tightens, then accelerate back up and so on. The first 10 seconds of the jump are plotted in Figures 7.43 and 7.44, where the origin represents the position of the jumper just before they leap from the platform.

a) **Calculate** the distance that the jumper travels in the first four seconds.

b) **Calculate** the displacement of the jumper after four seconds.

c) **Calculate** the distance covered by the jumper in the first 10 seconds.

d) **Calculate** how far the jumper is from the platform after 10 seconds (i.e. the displacement).

e) **Calculate** the average speed in the first four seconds.

f) **Calculate** the instantaneous speed at the six-second mark.

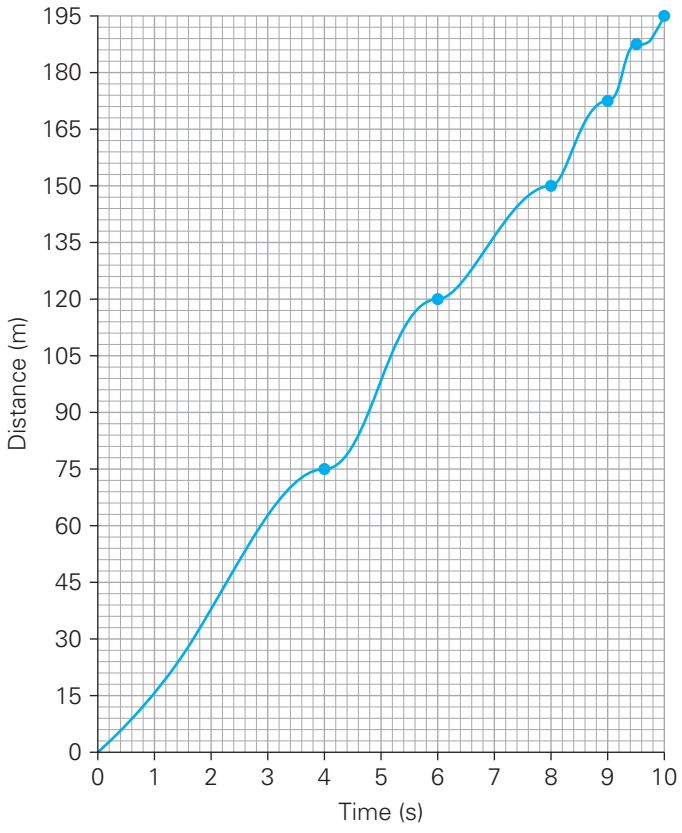

Figure 7.43 A distance–time graph of the bungee jumper

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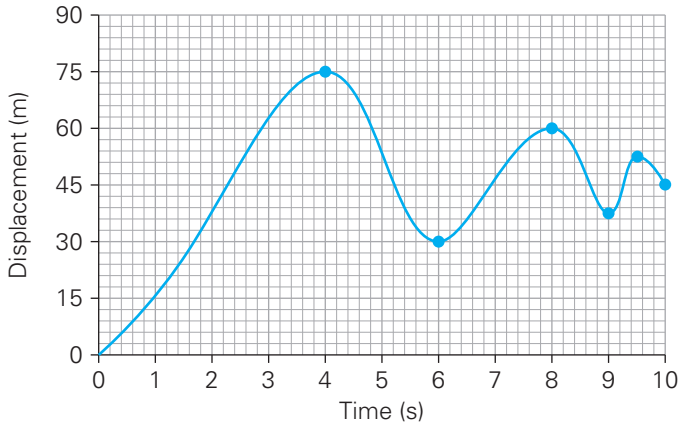

Figure 7.44 A displacement–time graph of the bungee jumper

Evaluating

10. A car starts from rest and accelerates at a constant rate in a straight line for five seconds to a final velocity of 54 km h^{-1}.

- **a)** **Calculate** the final velocity in m s^{-1}.
- **b)** **Calculate** the acceleration, in m s^{-2}, over the five seconds.
- **c)** Construct the velocity–time graph for this scenario and use it to **calculate** the displacement of the car by using the area under the graph.

Data questions

1. Using the velocity–time graph in Figure 7.45, **identify** the velocity of the object at the 10-, 40-, 90- and 140-second marks.
2. **Calculate** the acceleration of the object at the 10-, 40-, 80- and 110-second marks.
3. **Calculate** the displacement of the object from its origin after 170 seconds.
4. **Interpret** the velocity–time graph to describe the motion of the object in words.
5. **Deduce** a potential identity of the object.
6. **Propose** why the object is unlikely to be a bicycle.

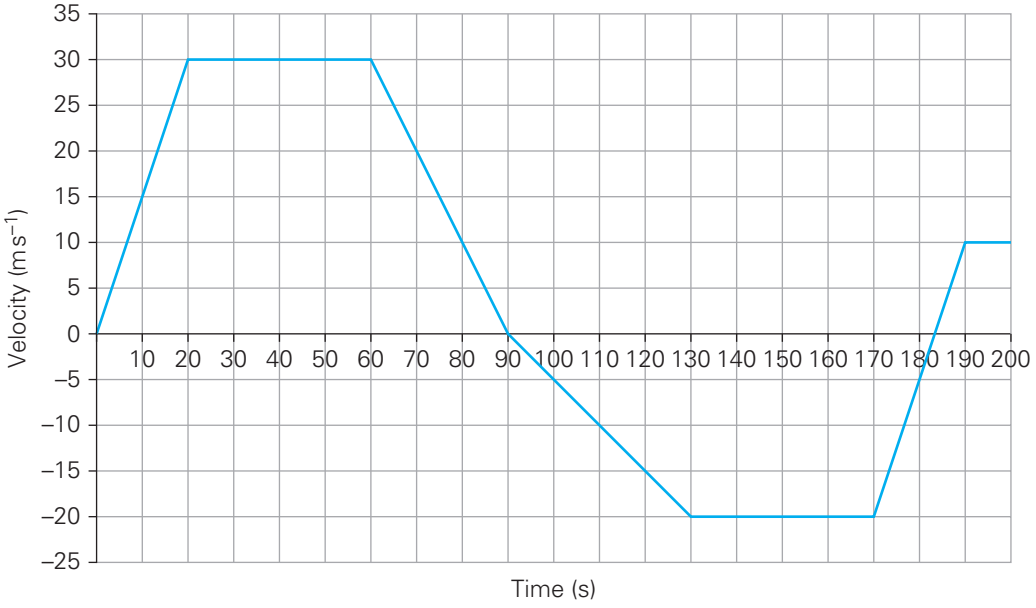

Figure 7.45 Velocity–time graph of an unknown object

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STEM activity: Transportation and energy usage

Background information

Transportation is a major part of everyday life, and whether it's a car, train, bus, plane or even a boat, energy is used in some form. While there has been a considerable push towards replacing fossil-fuel-burning engines with rechargeable batteries in the 2020s, many vehicles still use petroleum-based fuels as their source of energy. This makes it really important to be efficient in transportation design, including considering how energy is being transferred and transformed in the vehicle.

In petroleum engines, some energy is lost as heat going into the surrounding environment rather than directly into moving the wheels. Kinetic energy, which comes from the transformation of mechanical energy, is also lost as heat energy within the tyres and the road. It is estimated that approximately 75% of the energy input into a petrol-powered car engine is lost. Of this, the majority is engine losses, but there are also losses in the drivetrain and tyres. The aerodynamics of the vehicle shape also contributes to the energy efficiency issues.

DESIGN BRIEF

Decide on a mode of transportation and design improvements that will increase the energy efficiency of a model.

Figure 7.46 A car being charged with electricity

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Activity instructions

In groups of three, decide on a mode of transportation that you are interested in and research the ways in which energy is lost due to inefficiencies in design. Then, design and test improvements that could be made to improve the energy efficiency.

Suggested materials

- cardboard boxes
- cardboard
- tape
- various types of materials
- glue
- force meter
- measuring tape

Research and feasibility

1. Discuss and decide with your group which type of transportation you would like to learn about.
2. List all the ways in which energy goes in and then is used or lost.
3. Research ways to increase energy efficiency as it goes in and is used or lost. This can be done in a table – an example is shown below.

Energy	Possible issues	Ideas for design
e.g. Car Energy in – petrol	The engine can be dirty, and incomplete combustion can occur.	Recommend that the engine be regularly serviced.
e.g. Car Energy out – axle turning	The axle can have friction.	Lubricate the axle.
e.g. Car Energy out – car shape	Air resistance	Make the car bonnet smooth to allow less friction from air resistance.

Design and sustainability

4. Discuss available materials in your group and decide how you will design your initial prototype for preliminary testing.
5. Design your prototype without any efficiency ideas in place and decide how you will test this prototype.
6. Design a prototype, or changes to your initial prototype, that includes all efficiency ideas. You may choose to test them one by one or all together, depending on time and materials.
7. Discuss and justify why efficient design components are important for sustainability and how they contribute on a global energy scale.

Create

8. Construct your prototype and then complete testing.

Evaluate and modify

9. Using your energy equations, perform calculations on the energy you supplied to your prototype and consider how effectively this energy was used.
10. Explain to the class your prototype improvements and justify why your changes resulted in improved efficiency of energy transformation, or why they did not.

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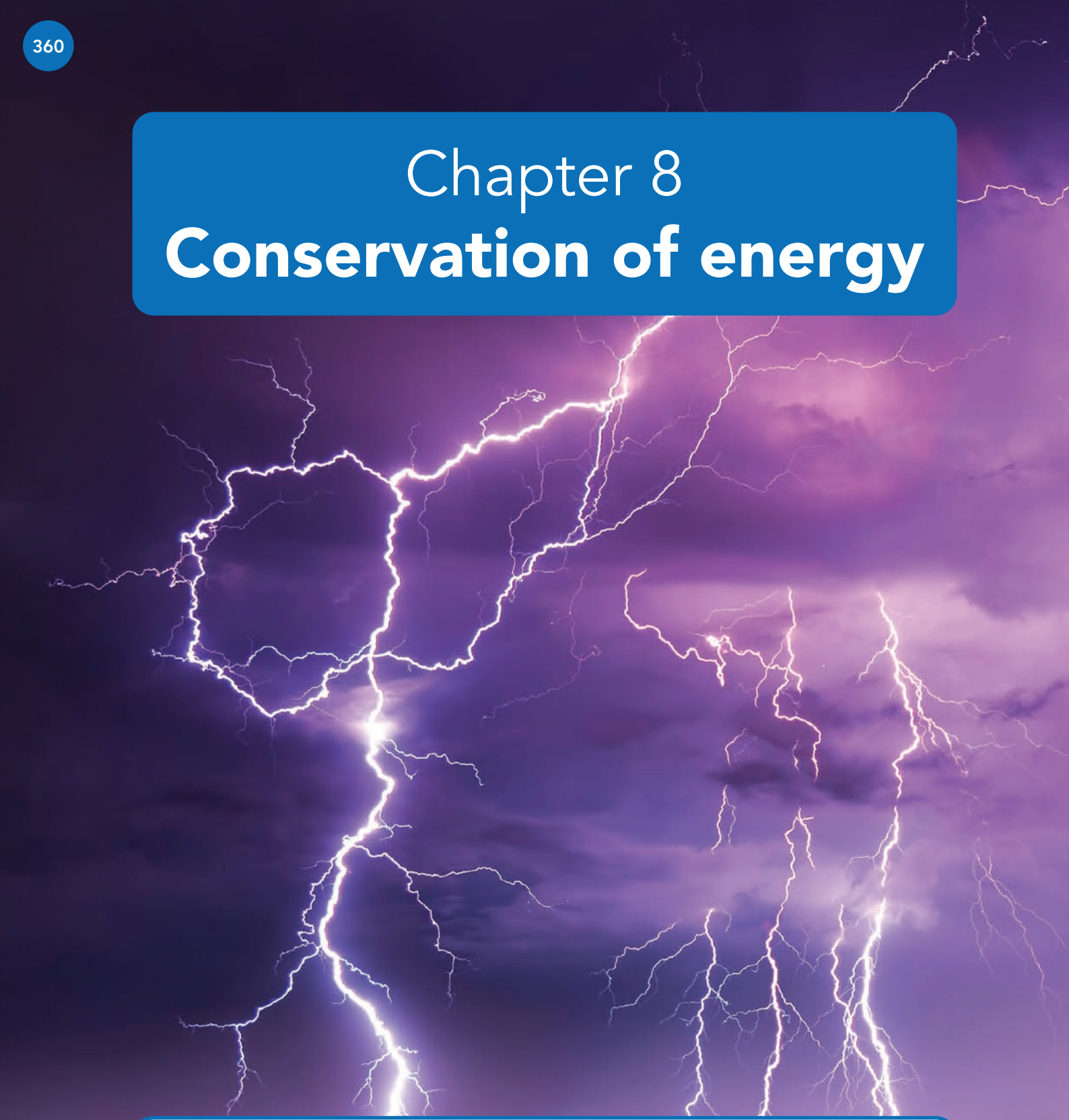
Chapter 8
Conservation of energy



Chapter introduction

Energy is all around us – radiating from the Sun, transporting us to where we need to go and powering our many devices. It is even stored in the food we eat. Much of our use of energy results in a loss of useful energy; thus, there is increasing pressure to be less wasteful and more efficient in our use of energy. This chapter will expand your knowledge on energy and its different forms. We will look at energy transfers and transformations as well as energy efficiency by applying the law of conservation of energy. Through the exploration of energy systems, we will compare the energy changes in physical events and look at everyday examples of energy in action and the physics involved.

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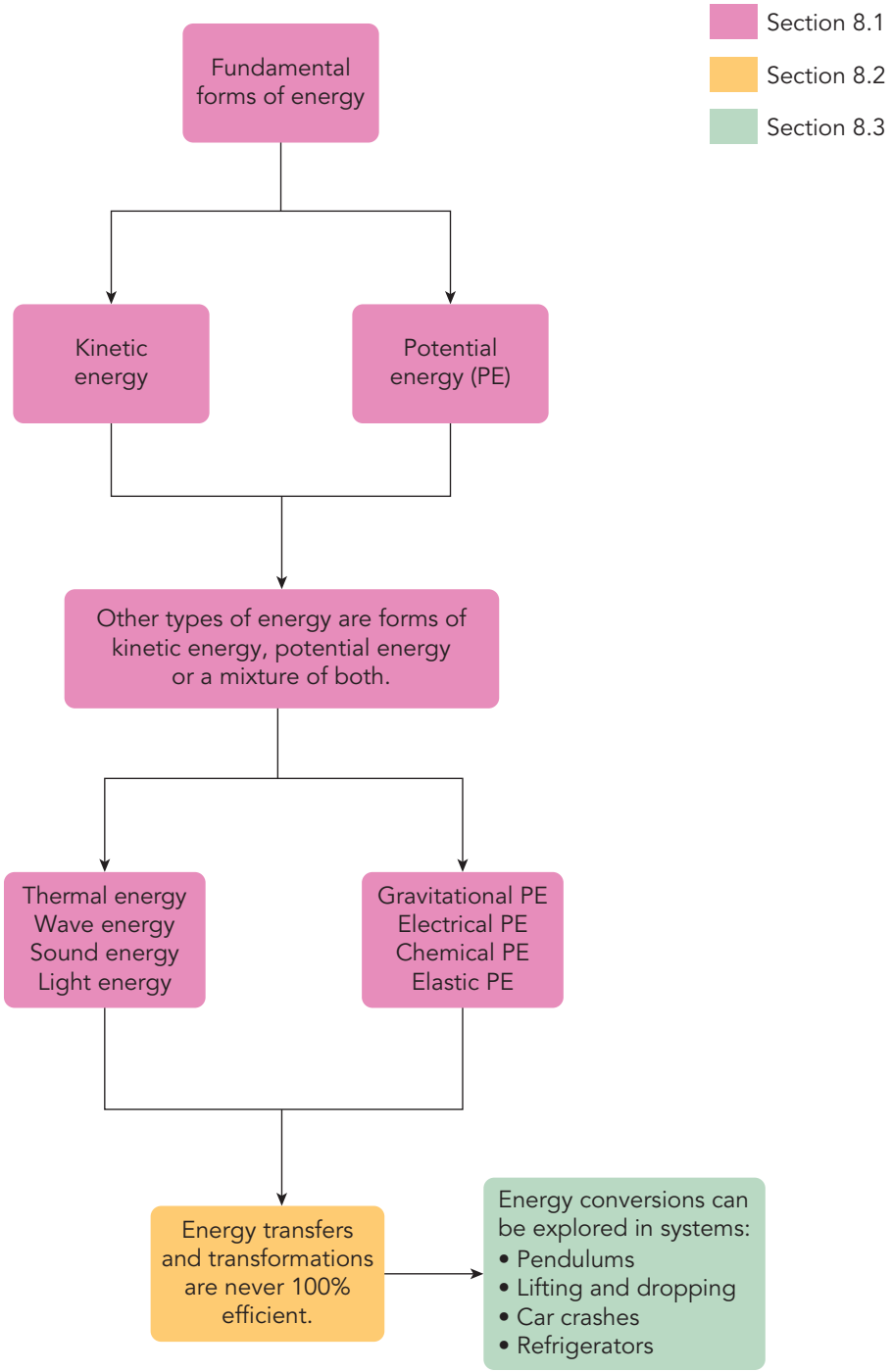
Chapter map



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Curriculum content

Physical sciences	
The law of conservation of energy can be applied to analyse system efficiency in terms of energy inputs and outputs, transfers and transformations	
• work is done when energy is transferred and transformed	8.1
• energy and work are scalar quantities that can be quantitatively determined by calculating gravitational potential and kinetic energy	8.1
• modelling the efficiency of energy transfers and transformations in a system using Sankey diagrams	8.2
• calculating energy transformations in a system, such as a ball falling onto a surface and rebounding, a pendulum swing, a roller-coaster changing height and speed around its track	8.3

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Glossary terms

efficiency
elastic potential energy
energy
gravitational potential energy
kinetic energy
law of conservation of energy
potential energy
Sankey diagram
system
useful energy
work

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8.1 Forms of energy

Learning goals

At the end of this chapter, I will be able to:

1. Define energy.
2. Recall the forms of potential and kinetic energy.

WORKSHEET Forms of energy

Everything happening around you, and even within you, is powered by energy. But what exactly is energy?

Energy and work

Energy is a word that can be used to describe when we move around or exert force on our surroundings. Objects can have energy too, and while energy itself cannot always be seen, changes in energy are easier to observe. In physics, **energy** is the capacity to cause change and is defined as the ability to do **work**. Energy is measured in joules, which has the symbol J. One joule is the amount of energy transferred when a force of one newton applied to an object causes it to be displaced by one metre. That is to say: 1 J = 1 N m.

energy the ability to do work

work the amount of energy transferred when an applied force causes an object to move some distance

Work is something that is done on or to an object when an applied force causes the object to move some distance. For example, if you push a motorbike up a hill, you will have done work.

Work can be quantified by the equation:

$$W = Fs$$

where W is work, measured in joules (J); F is the net force acting on the object, measured in newtons (N); and s is the displacement in the direction of the force, measured in metres (m).

For work to be done, the displacement needs to be in the direction of the force. Therefore, if a force is applied to an object and it does not move, no work is done. Force and displacement are vector quantities, which means they have magnitude and direction. However, work is a scalar quantity, which means it only has magnitude. Being a scalar quantity means that work, like energy, gives information on the total joules of energy exerted but does not provide any information on the direction.

Figure 8.1 Work is done on a motorbike when a force is applied to it, causing it to move some distance in the direction of the force. The larger the applied force or the greater the displacement, the more work is done.

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Worked example 8.1

Work

A weightlifter applies a force of 300 N to a barbell and lifts it 1.5 m off the ground. Calculate how much work is done by the weightlifter to lift the barbell.

Figure 8.2 Lifting weights requires work.

Working	Explanation
$F = 300$ N, $s = 1.5$ m	List the relevant data that has been provided.
$W = Fs$	Recall the definition of work and the equation.
$W = 300$ N $\times$ 1.5 m	Substitute the relevant data into the equation.
$W = 450$ J	Solve the problem, giving an answer with appropriate units. In this example, the work done by the weightlifter is equal to 450 J.

When a force acts on an object, it causes a change in energy because energy is transferred from other objects or transformed into different forms of energy. Worked example 8.1 shows that 450 J of work was done, which means that 450 J of energy was transferred or transformed. In this example, chemical potential energy in the weightlifter is transformed into the gravitational potential energy stored in the barbell. Chemical potential energy and gravitational potential energy are different forms of energy.

Energy has many different forms. Table 8.1 lists the different forms of energy that you would have learned about in previous years. All of these different forms of energy can be broadly classified as one of two types: kinetic energy or potential energy.

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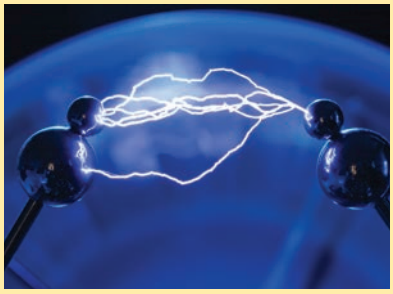
Forms of energy	
Kinetic energy	**Potential energy**
Kinetic (motion)	Chemical (including food energy and batteries)
Thermal	Nuclear
Radiant (electromagnetic radiation, including light)	Gravitational
Electrical (current) 	Elastic (including springs)
	Electric (static)
Mechanical energy	
Mechanical vibrational waves (sound, water waves)	

Note that mechanical energy is defined as the sum of the kinetic energy and the potential energy. Therefore, sound energy (that is, mechanical vibrational waves passing through an elastic medium) is a combination of kinetic and potential energies.

Table 8.1 The different forms of energy grouped into the two types of energy – potential energy and kinetic energy – and a mixture of the two

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Try this 8.1

Identifying forms of energy

Think back to when you ate breakfast this morning and try to identify the forms of energy involved with making and eating your breakfast – you will be surprised at how many there actually are.

Quick check 8.1

1. **Explain** what it means when work is done on an object.
2. A weightlifter applies an upward force of 100 N to a barbell and in doing so lifts it 1.2 m off the ground, holding it there for 10 seconds before dropping it.
   a) **Calculate** how much work is done by the weightlifter to lift the barbell.
   b) **Describe** how much work is being done by the weightlifter during the 10 seconds of holding the barbell at 1.2 m above the ground.

Kinetic energy

kinetic energy energy possessed by an object due to its motion

Kinetic energy is one of the two main types of energy. **Kinetic energy** (E_k) is the energy an object has due to its motion. When a force is applied to an object that then causes that object to move, work is being done – energy is being transferred. The energy transferred is known as kinetic energy and is possessed by all moving objects. The amount of kinetic energy that an object has depends on its mass and its velocity. Thus, the faster and/or heavier an object is, the more kinetic energy it will have.

Kinetic energy can be calculated using the following equation:

$$E_k = \frac{1}{2} mv^2$$

Figure 8.3 All objects in motion have kinetic energy. The amount of kinetic energy depends on how fast an object is moving as well as its mass.

where E_k is kinetic energy, measured in joules (J); m is the mass of the object in motion, measured in kilograms (kg); and v is the velocity at which the object is moving, measured in metres per second (m s^{-1}).

This equation shows that an increase in velocity has a more significant effect on the change to the amount of kinetic energy than the same increase in mass because velocity is squared in the equation.

In the equation, $\frac{v^2}{2}$ is proportional to the product of acceleration and displacement, or $a \times s$. Thus, for a change in kinetic energy, the equation can be written as:

$$\Delta E_k = m \times a \times s$$

A reminder that $F = m \times a$, and so the equation can be simplified to:

$$\Delta E_k = F \times s = W$$

And so, a change in kinetic energy is equal to work, $\Delta E_k = W$.

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Worked example 8.2

Kinetic energy

A cyclist has a mass of 100 kg and is travelling at 20 km h^{-1}. Calculate the amount of kinetic energy that the cyclist has.

Figure 8.4 A cyclist in motion possesses kinetic energy.

Working	Explanation
m = 100 kg, v = 20 km h^{-1}	List the relevant data that has been provided.
100 km h^{-1} ÷ 3.6 v = 27.78 m s^{-1}	Convert units to the SI base units (Standard International units) used in the equation. (Note that in this conversion the calculation has been rounded to four significant figures.)
$E_k = \frac{1}{2}mv^2$	Recall the definition of kinetic energy and the equation.
$E_k = \frac{1}{2} \times (100\text{ kg}) \times (27.78\text{ m s}^{-1})^2$	Substitute the relevant data into the equation.
E_k = 1388.89 J = 1389 kJ	Solve the problem, giving an answer with appropriate units. (Note that if the conversion to m s^{-1} is done as part of the substitution, the calculation will give 1388.89 J. Rounding it to four significant figures gives 1389 kJ.)

Quick check 8.2

1. **Identify** two factors that affect the amount of kinetic energy an object has and the effect they have.
2. A cricket player bowls a 160 g cricket ball at a speed of 145 km h^{-1}. **Calculate** how much kinetic energy is transferred to the ball.

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Potential energy

We now know that the man flying through the air in Figure 8.5 has kinetic energy as he is in motion. We even know that the amount of kinetic energy he has depends on his mass and speed. But what do we know about the people still sitting in the plane?

potential energy energy that is stored in an object due to its position and other factors, such as its mass, electric charge and internal stresses

gravitational potential energy energy stored in an object due to its position above the surface of Earth

The people sitting in the plane have stored energy due to their position high above the surface of Earth. This type of energy is called gravitational potential energy. **Potential energy** (E_p) is energy that is stored in an object due to its composition or position.

Figure 8.5 Forms of energy do not exist in isolation: a man moving through the air high above the ground has both kinetic and gravitational potential energy, while the people still sitting in the plane have more gravitational potential energy and less kinetic energy than the skydiver. All of the people still have chemical energy and thermal energy; however, they aren't as relevant in this example.

Gravitational potential energy

Gravitational potential energy is the energy stored in an object due to its position above the surface of Earth. Similar to the observer standing on top of the mountain, anything that is positioned above the surface of Earth has the potential to fall due to the effect of gravity. Therefore, the higher an object is above the surface of Earth, the more gravitational potential energy it has.

To calculate how much gravitational potential energy an object has, we use the following equation:

$$E_p = mgh$$

where E_p is the gravitational potential energy (GPE), measured in joules (J); m is the mass of the object, measured in kilograms (kg); g is the gravitational acceleration experienced by the object due to the strength of Earth's gravitational field (9.8 m s^{-2}); and h is the height of the object above the surface of Earth, measured in metres (m).

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Figure 8.6 As you ride on a roller-coaster, the amount of gravitational potential energy that you have is constantly changing, as is your kinetic energy.

From this equation, the amount of gravitational potential energy an object has depends on its mass and height above the ground. Say you wanted to lift an object from height A to height B, what would be the difference between the GPE (ΔE_p) at both heights? The change in GPE (ΔE_p) would equal the GPE at height B (E_{pB}) minus the GPE at height A (E_{pA}):

$$\Delta E_p = E_{pB} - E_{pA}$$

Substituting in the formula for GPE, we can see:

$$\Delta E_p = mgh_B - mgh_A$$

Remember that $F = ma$, and in this case the acceleration of the force is due to gravity, so we can say $F = mg$. Substituting this into our equation, we get:

$$\Delta E_p = Fh_B - Fh_A$$

Or:

$$\Delta E_p = F(h_B - h_A)$$

Moving the object from height A to height B is the same as moving an object a certain distance vertically, so $h_B - h_A = s$, and so:

$$\Delta E_p = Fs$$

We know that $W = Fs$, so:

$$\Delta E_p = W$$

Therefore, the change in GPE between two heights is equal to the amount of work done to move an object vertically.

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Worked example 8.3

Gravitational potential energy

A diver on the diving board has a mass of 60 kg.

a) If the diving board is 10 m above the ground, calculate the diver's gravitational potential energy.

b) When the diver is 0 m above the ground, calculate their gravitational potential energy.

c) Determine the work done, $W = \Delta E_p$, if the diver wants to go from 0 m back to the diving board 10 m above the ground.

Figure 8.7 A diver waiting to dive has gravitational potential energy due to their position relative to Earth's surface.

Working	Explanation
a) GPE at 10 m above ground	
m = 60 kg, h = 10 m, g = 9.8 m s^{-2} $E_p = mgh$ E_p = 60 kg × 9.8 m s^{-2} × 10 m E_p = 5880 J = 5.88 kJ	List the relevant data that has been provided. Recall the definition of gravitational potential energy and the equation. Substitute the relevant data into the equation. Solve the problem, giving an answer with appropriate units.
b) GPE at 0 m above ground	
GPE at ground level = ? GPE at ground level = 0 J	At h = 0 m, the gravitational potential energy is 0 J.
c) Work done	
Work done to climb back up to the board = ? Work done to climb back up to the board = 5.88 kJ	This means that if he wants to climb back up from the ground to a height of 10 m, there will have to be of 5.88 kJ of work done, as that is the difference in gravitational potential energy, ΔE_p.

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Elastic potential energy

Just as an object can have stored energy due to its position, it can also have stored energy due to its shape. **Elastic potential energy** is the energy stored in an object due to its shape, and usually results from the object either being compressed or stretched. When stretched or compressed, some materials store more energy than others.

elastic potential energy energy stored in an object due to its shape, usually resulting from the object either being compressed or stretched

Elastic potential energy (E_e) can be calculated using the following formula:

$$E_e = \frac{1}{2}kx^2$$

where E_e is the elastic potential energy (EPE), measured in joules (J); k is the elasticity constant, which is an indication of the object's stiffness and is measured in N m^{-1}; and x is the linear length by which it has been expanded or compressed relative to its equilibrium position, measured in metres (m).

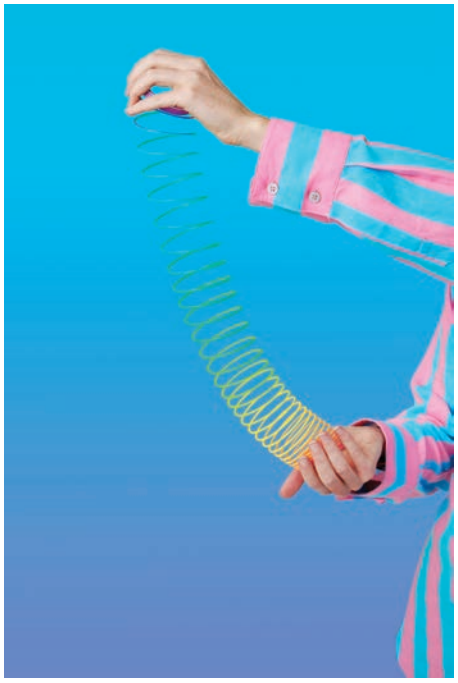

Figure 8.8 A stretched slinky has elastic potential energy. When released, the slinky will return to its original position.

This equation shows us that the amount of elastic potential energy possessed by an object depends on the elasticity of the material, as well as the displacement of the material due to compression or stretching. Again, some force (F) is needed to stretch or compress the material, and there is a displacement (s); thus, work is being done. The amount of work is equal to the elastic potential energy, where $\Delta E_e = W$.

Worked example 8.4

Elastic potential energy

A bow has an elasticity constant of 2000 N m^{-1}. It is stretched by 30 cm. Calculate the amount of elastic potential energy stored in the bow.

Figure 8.9 A stretched bow stores elastic potential energy.

Working	Explanation
k = 2000 N m^{-1}, x = 0.30 m	List the relevant data that has been provided.
$E_e = \frac{1}{2}kx^2$	Recall the definition of elastic potential energy and the equation.
$E_e = \frac{1}{2} \times (2000 \text{ N m}^{-1}) \times (0.30 \text{ m})^2$	Substitute the relevant data into the equation.
E_e = 90 J	Solve the problem, giving an answer with appropriate units.

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Section 8.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 8.1 questions

Remembering

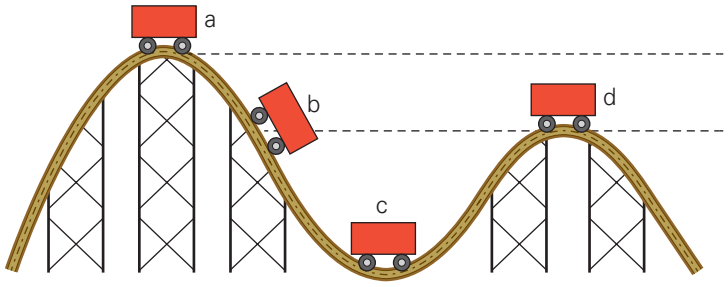
1. **Define** the term 'energy'.
2. **Recall** what kinetic energy is.
3. **Name** three everyday objects that have elastic potential energy.

Understanding

4. **Calculate** the displacement of a tennis ball hit with a constant force of 333 N by a tennis player who does 100 J of work in doing so.
5. **Explain** how work done relates to lifting an object against gravity using the formula $W = \Delta E_p$.

Applying

6. **Describe** the energy changes in the roller-coaster below at points a, b, c and d.



7. **Classify** the following as possessing either kinetic energy or potential energy.
   a) The moving (or spinning) blades in a blender
   b) Books sitting on a bookshelf
   c) Hot water in a kettle
   d) The sound coming from a radio
   e) A cheeseburger

Analysing

8. **Compare** gravitational and elastic potential energy.
9. **Organise** the following items from having the most to the least amount of gravitational potential energy.
   - An apple hanging in a tall tree
   - An apple lying under a tree
   - An apple in a fruit bowl on a table

Evaluating

10. In the case of a person pushing against a rock wall, **justify** why no work is being done.

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8.2 Energy transfers and transformations

Learning goals

At the end of this section, I will be able to:

1. Calculate the efficiency of energy output.
2. Describe energy transfers and transformations.
3. Interpret Sankey diagrams, illustrating energy transfers.

WIDGET
Energy conversion flow diagrams

WORKSHEET
Energy transfers and transformations

Energy is constantly changing from one form to another. For example, the characteristic lights and sounds produced by fireworks are the result of a range of energy transformations. When a firework explodes, thermal energy, in the form of a lit fuse, in addition to chemical potential energy, is transformed into heat, light and sound energy, as well as kinetic and gravitational potential energy.

Not all energy transformations are this complex. For example a toaster transforms electrical energy to thermal energy, which toasts the bread by radiation. Regardless of how simple or complex the transformations are, energy is conserved in all energy conversions. In other words, all conversions abide by the **law of conservation of energy** in that energy can be neither created nor destroyed; it can only be transferred or converted from one form of energy to another.

law of conservation of energy
a scientific law that states that energy can be neither created nor destroyed, only converted from one form of energy to another

Energy efficiency

The optimisation of many machines involves ensuring that as much of the input energy is transferred or transformed to the output energy that is required. Consider the incandescent light globes in Figure 8.10. Only about 10% of the total electrical energy input is transformed into visible light energy. The remaining 90% is transformed into thermal energy. As producing thermal energy is not the main use of a light globe (producing light is!), the thermal energy produced is said to be wasted energy. This loss of useful energy does not mean that energy has disappeared, because the waste (thermal) energy is still accounted for according to the law of conservation of energy. However, the high proportion of wasted energy (90%) shows that the energy transfer is inefficient.

Figure 8.10 Incandescent light globes can be quite inefficient.

Achieving a 100% efficient energy conversion is extremely unlikely, especially for machines that do work, because energy in some form is almost always lost to the system. Consider the soccer ball being dropped from a height onto a concrete surface in Figure 8.12. At its maximum height, the ball has a large amount of gravitational potential energy. When the ball is dropped, this gravitational potential energy is converted to kinetic energy, which reaches a maximum just before the ball hits the ground. As the ball hits the ground, the kinetic energy is converted into elastic potential energy. This is converted back into kinetic energy as the ball bounces up again. If this system was 100% efficient, the ball would bounce back up to its starting height and have the same amount of gravitational potential energy as it did before being dropped. We know that this is not the case because with each bounce, the ball reaches a lower maximum height until eventually it comes to a stop.

Figure 8.11 Fireworks are the result of many energy transformations.

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Figure 8.12 The bounce of a soccer ball on a surface is not 100% efficient because energy is lost from the system.

Let's look at how energy is lost from this system. First, as the ball is falling towards the ground, it is encountering air particles. Contact with these particles results in friction and heat – thus, energy is lost as heat to the surrounding air particles. When the ball bounces, it creates a sound, and there is also friction between the ball and the ground. Therefore, each successive bounce of the ball has less energy than the preceding bounce. As a result, the ball slows down, before coming to a stop when all the energy initially possessed by the ball is lost to the system.

Try this 8.2

Energy efficiency of bouncy balls

Aim

To investigate which type of bouncy ball is most energy efficient.

Materials

- a range of bouncy balls
- metre rulers

Method

Design an experiment that will test the rebound height of a range of bouncy balls. In a group, discuss how you will carry out this experiment, and write a step-by-step method.

Results

1. Draw a results table for your experiment.
2. Produce a suitable graph for your experiment.

Discussion

1. By using the energy efficiency equation, calculate the efficiency of each type of ball. Use the drop height and the rebound height in your calculations.
2. Identify sources of uncertainty in your experiment.
3. Suggest how your experiment may be improved.
4. Describe the effect of the surface on the efficiency of the bouncing ball.

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Explore! 8.1

Energy transfer in sport

There are many sports in which performance depends on the interaction of a human and an object – for example, a cricketer's technique when bowling or batting, or the technique used when throwing or kicking an Australian Rules football. In individual sport, it might be the interaction of a pole vaulter and the pole or of an archer and the bow. Performance in these sports requires peak energy efficiency in the energy transfer processes.

Consider the types of energy used and explain how energy is optimally transferred between:

a) a pole and a pole vaulter
b) an archer and an arrow.

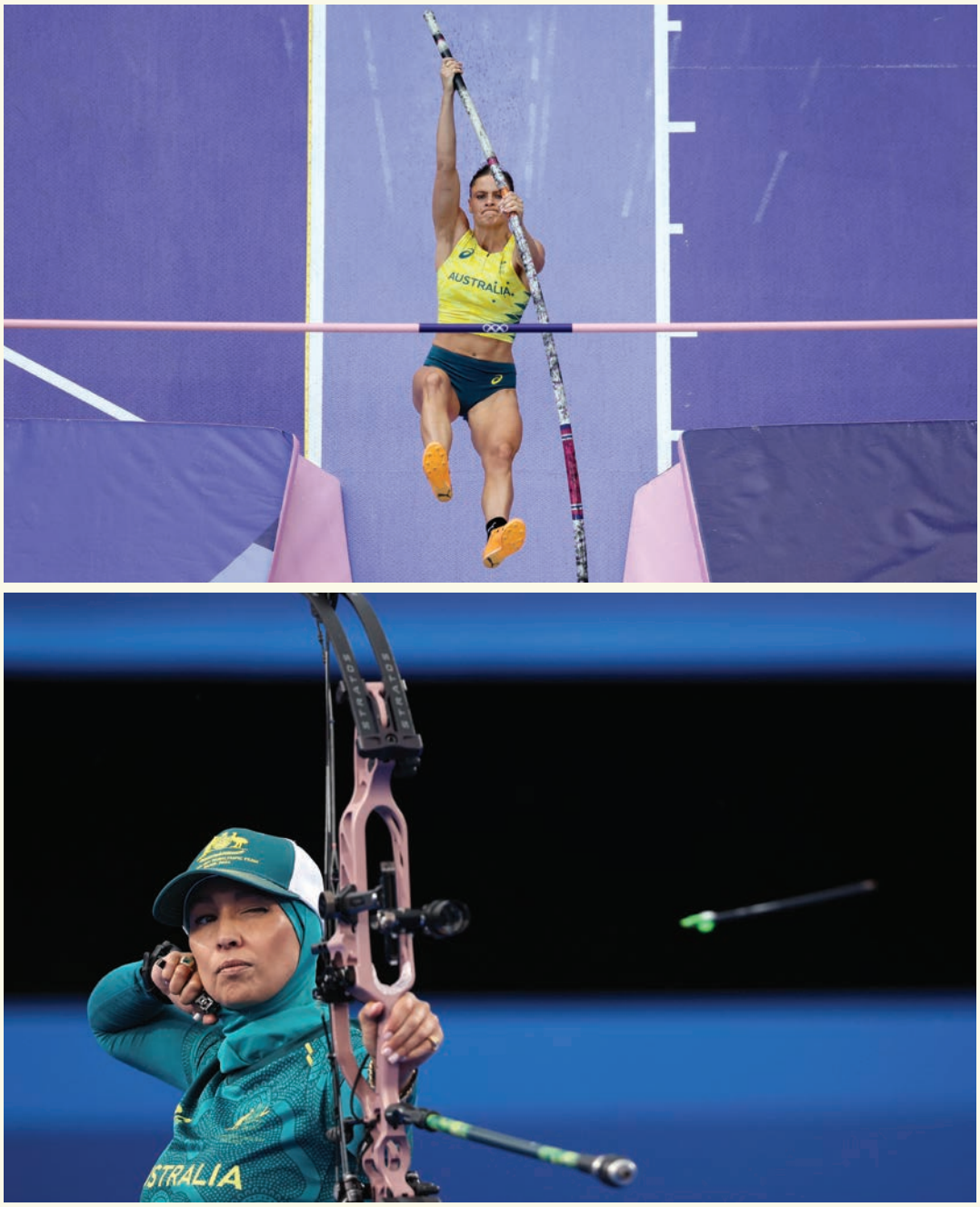

Figure 8.13 Athletic performance can be improved with efficient energy transfer.

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Did you know? 8.1

Earth ovens

Some communities of Aboriginal and Torres Strait Islander people use earth ovens as a method of transferring heat energy to cook food by conduction, convection and radiation. A hole is made in the ground and lined with hot rocks that have been heated in a fire. The food is then placed on the hot rocks and often covered with leaves and more rocks to insulate the heat, creating an oven environment.

Like all ovens, the earth oven is not 100% efficient; energy is lost from the cooking process as heat and light to the surroundings as well as contributing to other chemical reactions. However, earth is an excellent insulator due to pockets of air in the soil. This makes earth ovens an energy-efficient method of cooking food.

WORKSHEET Source of energy

WORKSHEET Evolution of cars

Energy efficiency in housing

In our homes, there are machines or appliances that we use in our daily lives. Some appliances use little energy, and others use a lot. Some are very efficient, and some are inefficient. The energy source for most appliances in the typical home is electricity, although gas, solar energy and the chemical energy from batteries are also widely used.

One of the big expenses in maintaining a home is the cost of energy. Electricity and gas are both expensive; however, solar energy is free after solar panels have been installed. Solar panels can transform the light energy from sunlight into other useable types of energy such as electricity or thermal energy.

Figure 8.14 This house has solar panels on the roof to generate electricity. It also has two solar thermal panels for generating hot water.

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Energy ratings

Most appliances in Australia have an energy rating label as part of the Australian Government's Equipment Energy Efficiency Program. The energy rating label may take one of the three forms depicted in Figure 8.15 – a rating out of six stars, a rating out of 10 stars for super-efficient appliances, or a 10-star pool pump rating.

The more stars an appliance has, the more energy efficient it is – that is, the more input energy that is transformed to useful output energy. The number of stars is determined by the energy consumption value in kilowatt hours (kWh) per year, which is also provided on the label. The lower the energy consumption value, the higher the energy rating.

Figure 8.15 Three types of energy rating labels found on appliances in Australia

Try this 8.3

Home electricity audit

Use the Australian Government's 'Energy rating calculator' website to audit the energy efficiency of appliances around your house, such as your TV, washing machine, dishwasher and fridge. Compare how much it costs to run each appliance for a year.

Which appliance costs the most to use? Compare one appliance and its yearly running costs with that of a classmate's appliance. Who has the more cost-saving model?

Quick check 8.3

1. **Explain** how you can easily compare the energy efficiency of two models of a washing machine.
2. **Explain** why it is beneficial to buy energy-efficient appliances, even though they can be more expensive than other models.

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Calculating energy efficiency

efficiency the percentage of input energy that is converted to useful energy by a machine

useful energy the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it produces

The **efficiency** of a machine is a measure of how good the machine is at converting the input energy to **useful energy**. The percentage of input energy that is converted to useful energy is used to give the machine an efficiency rating.

The formula used to calculate the efficiency rating of a machine is:

$$\text{efficiency (\%)} = \frac{\text{useful output energy (J)}}{\text{input energy (J)}} \times 100$$

Figure 8.16 Hiking up hill converts chemical energy into kinetic energy. The higher one climbs a hill, the more kinetic energy has been converted to gravitational potential energy.

Worked example 8.5

Energy efficiency of a kettle

A kettle uses 261 500 J of electrical energy to heat 500 mL of water. If the thermal energy of the water is 209 200 J, calculate the efficiency of the kettle. For simplicity, assume that the water starts with no thermal energy.

Working	Explanation
Useful output energy = 209 200 J Input energy = 261 500 J	List the relevant data that has been provided.
$\text{Efficiency (\%)} = \frac{\text{useful output energy}}{\text{input energy}} \times 100$	Recall the definition of energy efficiency and the equation.
$\text{Efficiency (\%)} = \frac{209\,200}{261\,500} \times 100$	Substitute the relevant data into the equation.
Efficiency = 80%	Solve the problem, giving an answer with appropriate units.

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Worked example 8.6

Energy efficiency of muscles

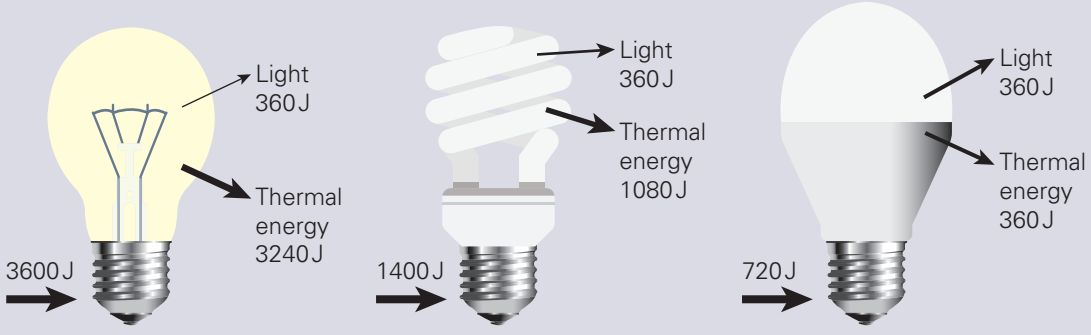
A girl runs upstairs and uses up 4000 J of energy from food she has eaten. If this energy is used to output 1000 J of gravitational potential energy, calculate the efficiency of her muscles.

Working	Explanation
Useful output energy = 1000 J Input energy = 4000 J	List the relevant data that has been provided.
Efficiency (%) = $\frac{\text{useful output energy}}{\text{input energy}} \times 100$	Recall the definition of energy efficiency and the equation.
Efficiency (%) = $\frac{1000}{4000} \times 100$	Substitute the relevant data into the equation.
Efficiency = 25% The other 75% would be waste energy, lost mainly as thermal energy as she climbs the stairs.	Solve the problem, giving an answer with appropriate units.

Try this 8.4

Calculating energy efficiency

Calculate the energy efficiency of each of the globes shown. State which globe is no longer recommended for household use and justify your choice.



Making thinking visible 8.1

See, think, wonder: Smartphones

Scientists and engineers continually strive to make smart devices, such as smartphones, more energy efficient. That is, when you charge your smart device, not only does the battery last longer, but the chemical energy is also being used to efficiently perform the tasks required of the device.

See: What do you see that scientists and engineers have done to make smart devices more energy efficient?

Think: What thoughts come to mind as you consider these strategies?

Wonder: Given the progress towards energy-efficient smart devices, what do you wonder about the future of energy-efficient smart devices?

The *See, think, wonder* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Quick check 8.4

1. **Define** 'energy efficiency'.
2. Copy and complete the following table by giving an example of the useful energy and waste energy produced by each device.

Device	Useful energy output	Waste energy output
Light globe		
Car		
Lawn mower		

3. A light globe uses 3000 J of electrical energy. Of this, 600 J is transformed into light energy and 2400 J is transformed into thermal energy. **Calculate** the energy efficiency of this globe.

Sankey diagrams

Sankey diagram a flow chart that represents the flow of energy through a system

A **Sankey diagram** is a flow chart that represents the flow of energy through a system. A Sankey diagram has a wide arrow at its base, which represents the energy input into a system. The flow diagram then branches off into two or more arrows, the size and thickness of which are directly proportional to the amount of output energy in that form.

For example, Figure 8.17 shows a Sankey diagram for an incandescent light globe where only 10% of output energy is in the useful form of light. The Sankey diagram shows that most of the electrical energy is transformed into thermal energy (thicker arrow), which is said to be lost or wasted energy.

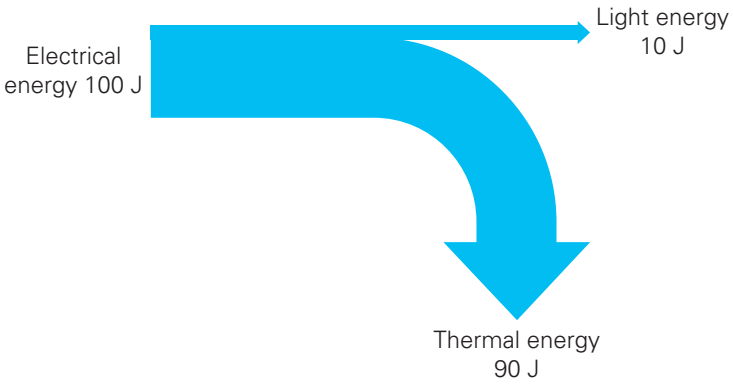

Figure 8.17 A Sankey diagram for an incandescent light globe showing the amount of input energy (100 J) as well as the amount of output energy in its various forms.

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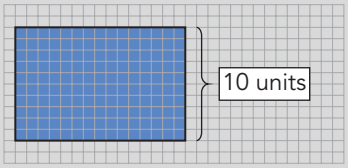
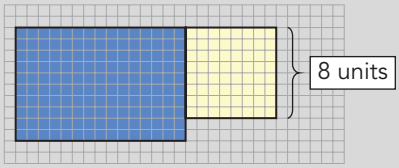
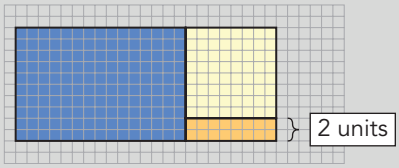
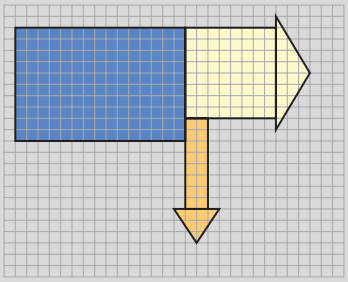
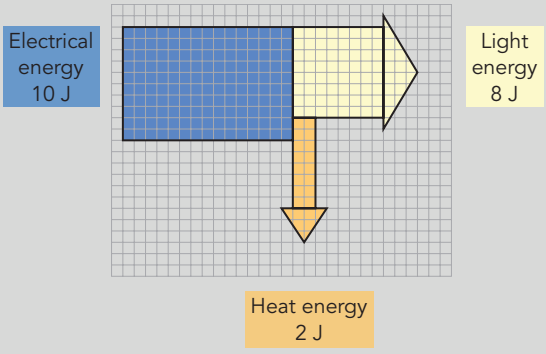
Worked example 8.7

Drawing a Sankey diagram

Draw the Sankey diagram of an energy-efficient light globe with an input energy of 10 J, an output energy of 8 J in the form of light and a wasted output of 2 J in the form of heat.

Working	Explanation
	The height of the box represents the amount of energy that is put in. In this case it is 10 J, so it should be 10 units high. Note that the length of the box does not matter.
	The height of the next box represents the amount of useful energy. In this case, it is 8 units high.
	The height of the final box represents the amount of wasted energy. In this case, it is 2 units high.
	Rotate the wasted energy box 90° clockwise so it points down. This shows that it is wasted energy. Add arrows to the output boxes.
	Finally, add the labels.

Quick check 8.5

1. **Outline** the energy changes that take place when you jump on a trampoline. **Explain** why you do not bounce back up to the same height after successive bounces.
2. **Calculate** the efficiency of an electric stove that has an input of 1500 J of energy and produces 200 J of light energy and 1300 J of thermal energy.
3. **Draw** a Sankey diagram for the electric stove in Question 2.

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Section 8.2 questions

Remembering

1. **Define** the term 'useful energy'.
2. **Recall** the energy transformations that occur when fireworks explode.
3. **State** what usually happens to wasted energy.

Understanding

4. An organism uses 500 J of chemical potential energy stored in its body to produce 125 J of kinetic energy so that it can climb a tree. **Calculate** the energy efficiency of this process.
5. An electric kettle has an energy efficiency of 89%. **Calculate** how much electrical energy is required to produce 1068 J of thermal energy.
6. Figure 8.18 shows a Sankey diagram for a light globe.
   a) **Identify** the useful energy output that the light globe is designed to produce.
   b) **Recall** the effect that the wasted energy has on the surrounding air.
   c) **Calculate** the efficiency of this light globe.

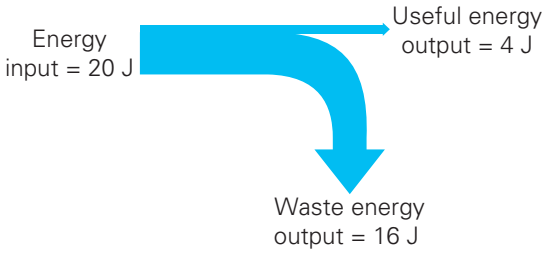

Figure 8.18 Sankey diagram for a light globe

Applying

7. A car has an energy efficiency of 35%. **Explain** what this means in terms of energy.
8. A washing machine has an energy rating of four out of six stars. **Describe** why it might not have earned six out of six stars.
9. **Explain** how the law of conservation of energy still applies to a system despite energy being 'lost' during a transformation.
10. On cold days, some of the heat transferred from a hot car engine is used to warm the air inside the car. **Describe** the effect that this has on the overall efficiency of the car engine.

Analysing

11. **Organise** the following processes from the highest amount of energy to the lowest:
    Falling raindrop: 85×10^{-6} J
    Cosmic ray: 1.6×10^{-9} J
    Car travelling on the Albany Highway: 4.00×10^{5} J
    Strong earthquake: 1.0×10^{16} J
    Falling snowflake: 6.50×10^{-7} J

Evaluating

12. Incandescent light bulbs convert 10% of their input energy into light energy, whereas LEDs (light-emitting diodes) convert 60% of their input energy into light energy. **Determine** which type of light bulb is more energy efficient.
13. As Kryon slides down a playground slide, the amount of kinetic energy that he gains is less than the amount of gravitational potential energy that he loses.
    a) **Predict** where the missing energy goes.
    b) **Propose** what Kryon can do to minimise the amount of wasted energy.

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8.3 Exploring energy in systems

Learning goal

At the end of this section, I will be able to:

1. Explore energy transfers in pendulums, cranes, car crashes and refrigerators.

WORKSHEET Exploring energy in systems

Our understanding of energy conversions can be applied to systems. In this context, a **system** is defined as a portion of the universe that is being analysed. Within a system, energy is conserved, and thus all energy conversions can be accounted for.

system a portion of the universe that is being analysed

Let's have a look at the energy conversions of physical events in some everyday systems.

Pendulums

The pendulum is a classic example of the law of conservation of energy in action: gravitational potential energy is converted to kinetic energy and back. This repeats over and over again as the pendulum swings.

Figure 8.19 A pendulum

A pendulum is a massless string attached to a pivot point with a bob on the other end. The bob is a dense object that accounts for all of the mass of the system. The effects of air resistance acting on the pendulum and friction in the pivot are ignored, and so this is an idealised system.

Pendulums are excellent models for systems where energy is successively transformed between gravitational potential energy and kinetic energy. When the mass is drawn upwards or outwards, the system gains gravitational potential energy. When the mass is released, the energy is converted into kinetic energy due to gravity pulling the bob down. Kinetic energy in the bob causes it to swing up in the opposite direction, during which its kinetic energy is once again converted into gravitational potential energy. This cycle repeats itself a number of times until, in a real pendulum, the bob comes to a rest.

Figure 8.20 A pendulum tracing circles in sand as its motion decreases before coming to a stop due to friction

The reason that the bob slows down and eventually stops is that, with each successive energy conversion, energy is lost to the system as heat and sound, primarily due to air resistance.

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Explore! 8.2

Perpetual motion machines

A perpetual motion machine is a hypothetical machine that remains in motion indefinitely. Many people have attempted to make a perpetual motion machine, but none will ever succeed as perpetual motion machines are physically impossible because we are unable to remove all forms of friction.

According to the law of conservation of energy, energy can be neither created nor destroyed, and energy needs to be applied to keep a machine moving indefinitely because of wasted energy. We are not able to remove all forms of friction – except in the microscopic world. Therefore, if no energy is applied to a system that eternally produces energy, that system will violate the law of conservation of energy.

Research perpetual motion machines to answer the following questions.

1. Is it possible to create a perpetual motion machine? Why or why not?
2. In superconductors, charge can flow without any resistance. It is possible to make a superconducting ring with a persistent current that will continue to circulate forever. Is this an example of a possible perpetual motion machine? Can we use this to do any useful work? Explain your reasoning.

Quick check 8.6

1. **Describe** how a playground swing can be considered a pendulum.
2. **Explain** why a person needs to be pushed on a swing to continue to reach the same height.
3. Using the law of conservation of energy, **explain** what happens to the energy lost in a system involving a pendulum.

Figure 8.21 A container lifted by a crane in a shipyard has kinetic and gravitational potential energy.

Lifting and moving

We saw earlier in this chapter that work is done on an object when a force applied causes it to move some distance.

A crane is used to lift and lower heavy or large objects, such as the containers in a shipyard. Let us look a bit closer at the work and energy conversions that are taking place.

While a container is being lifted, it will have some kinetic energy as the object is in motion. Additionally, the container increases its height above the surface of Earth, so it gains gravitational potential energy. The law of conservation of energy states that energy cannot be created or destroyed, so where does this energy come from?

The energy gained by the container is due to work being done on it. The applied force in this situation would be the tension force in the chain lifting it up. Some initial work is required to set the container in motion, thus transferring kinetic energy to the system. As more work is done on the container, it gains more energy – gravitational potential energy.

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What would happen if the chain broke and the container dropped to the ground? Naturally, there would be a change in gravitational potential energy as the container's height decreases. As there is a change in energy in the system, work is being done, so a force must be being applied. The force doing work on the container when it falls is the gravitational force, arising from gravity pulling the container down.

Quick check 8.7

1. Use a flow chart to **illustrate** the changes in energy that occur when a weightlifter lifts a barbell and then drops it.
2. **Explain** how work is done on a falling object.

From the law of conservation of energy, we know that the total energy in a system must be conserved. Thus, gravitational potential energy is converted into kinetic energy as the object accelerates towards the surface of Earth. Upon landing, the gravitational potential energy is reduced to zero, and all of the kinetic energy is converted into thermal energy and sound energy.

Car crashes

Moving cars have large amounts of kinetic energy due to their motion. This kinetic energy must be transferred and transformed in a car crash.

Collisions obey the law of conservation of energy, so the large amounts of kinetic energy that moving objects hold have to go somewhere. The damage caused by collisions results from the transfer of large amounts of energy over very short distances and time intervals. Remember that work is defined as the amount of energy transferred when an applied force causes an object to move some distance. The size of the force is proportional to the amount of work done, and thus proportional to the amount of energy transferred. In other words, the more energy transferred, the more force applied. As the distances and the time involved are reduced, the forces involved increase.

Figure 8.22 What happens to a car's kinetic energy in a collision?

In Figure 8.22, a car has crashed into a tree. The car had kinetic energy from its initial motion, the magnitude of which depends on its mass and speed. After the collision, both the car and the tree are stationary, and thus have no kinetic energy. From the law of conservation of energy, we know that energy is not destroyed, so work must have been done on the car to transfer that energy. It is the force of the tree on the car that brings it to a stop; therefore, it is the work done by the tree on the car that reduces the car's energy to zero. As the force produced in a collision is the primary danger and cause of injury, cars have many safety features in their design to reduce the impact of the force on occupants. Let us look at some of those features.

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Crumple zones

Crumple zones, as the name suggests, are sections of the car designed to crumple in a collision. They crumple when they absorb some of the energy transferred during the collision. This results in less energy being transferred, and thus less force applied, to the occupants of the car, reducing the severity of injuries.

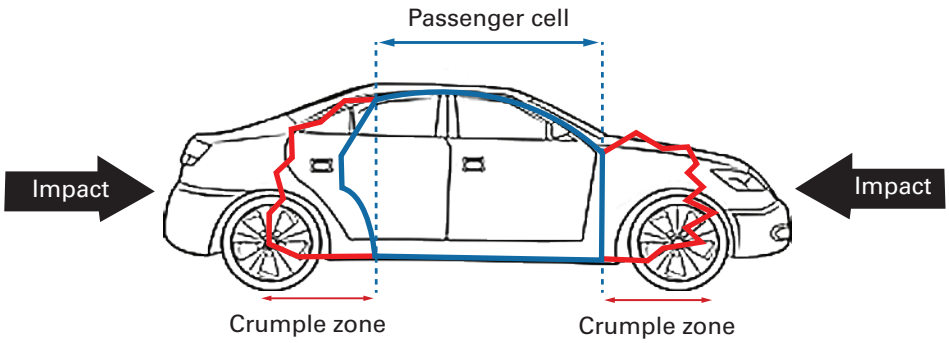

Figure 8.23 Crumple zones are usually located at the front and back of cars, and are designed to absorb some of the energy in a collision.

To protect the driver and passengers, the passenger cell or cabin is made of stronger materials that are not designed to crumple. Crumple zones are usually, but not limited to, the front and back of the car, as these are the sections of the car that are most likely to be affected by a crash.

By deforming, crumple zones not only absorb some energy (as work is being done to crumple the car) but also increase the time (and thus the distance) over which the collision occurs. As we know by looking at the equation for work ($W = Fs$), force is inversely proportional to displacement. Therefore, for a set amount of work, by increasing the displacement, there is a decrease in the force applied.

Figure 8.24 A seatbelt is a safety device in car that prevents injuries by helping you come to a stop safely.

Seatbelts

In a collision or sudden stop, an unrestrained object will continue to move in its original direction until a force is applied to make it stop – this is inertia as described by Newton's first law of motion in Chapter 7. Seatbelts make sure that the passenger stops moving in a collision by applying that force. As discussed above, the main purpose of car safety features is to reduce the size of the applied force and in doing so reduce the severity of injuries caused during collisions. Seatbelts have a three-point anchor system and are designed to increase the area over which the force is applied. By spreading the force, the potential for injury is reduced significantly. Seatbelts also stretch slightly, and this increases the stopping distance and reduces the force on occupants.

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Airbags

Airbags are another car safety system designed to protect occupants in a collision by reducing the force applied in bringing them to a stop. As seatbelts only apply a force to the body, the head will continue in its original path of motion. Therefore, airbags are in place primarily to protect the occupants' heads from hitting the dashboard, steering wheel or windscreen.

Airbags are cushions that inflate with a gas in the event of a collision. The inflated airbag increases the area over which the force is applied, as well as increasing the time and distance over which the force acts. All of these factors reduce the size of the force experienced by the occupant, which reduces the severity of injuries caused in a collision.

Figure 8.25 An airbag inflating on impact protects a head from hitting the steering wheel or windscreen.

Quick check 8.8

1. **Discuss** what would happen if a car stopped suddenly and the occupant was not wearing a seatbelt.
2. **Explain** how energy is conserved in a collision.

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Figure 8.26 A refrigerator is a common electrical appliance that transfers thermal energy to keep our food cold and fresh.

Refrigerators

The electric refrigerator has been keeping our food and drinks cold and fresh since the early 1900s. It works by transferring thermal energy from inside the fridge to outside the fridge through the use of a coolant.

Thermal energy moves from objects with higher temperatures to objects with lower temperatures until a thermal equilibrium is reached. Work is required to move the thermal energy in the system and requires energy and force. The energy is provided by electrical energy, which is transformed into kinetic energy, which causes the pumps to apply a force to the coolant, resulting in its circulation. Wasted energy would be thermal and sound energy.

A refrigerator has a closed system of pipes filled with a liquid coolant that undergoes pressure changes to direct the thermal energy away from the fridge contents. The key to the functioning of a refrigerator is a coolant, or refrigerant. This is a substance with a low boiling point, so it changes between the liquid and gas phases as it passes through the refrigerator system. The role of the compressor pump is to compress the coolant vapour. This raises the vapour's pressure and temperature. The compressed vapour gas is pushed through the coils of the condenser on the outside of the refrigerator. When the hot pressurised gas in the coils of the condenser meets the cooler air in, for example, the kitchen, it becomes a liquid.

The now-warm liquid cools down quickly as it expands rapidly through the expansion valve. This now-very-cool liquid goes into the evaporator coils inside the freezer and the fridge. The coolant absorbs the thermal energy inside the fridge when it flows through the evaporator coils, cooling down the air inside the fridge, and heating the coolant, which then evaporates to a gas again due to its raised temperature. This low-pressure vapour then flows back to the compressor pump, where the cycle starts all over again.

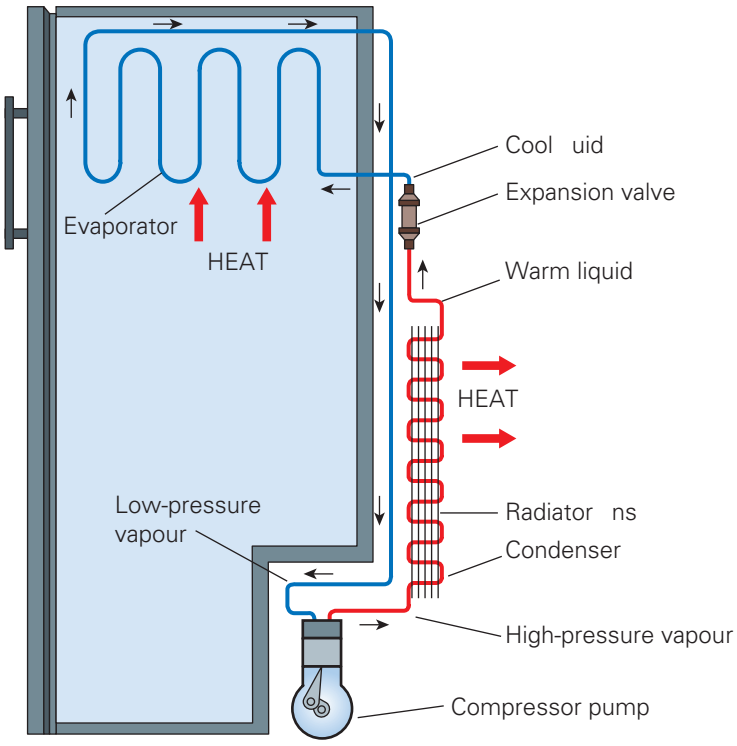

Figure 8.27 The cooling system of a refrigerator

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Quick check 8.9

1. **Explain** how the changes in pressure facilitate the cooling of air inside a fridge.
2. **Demonstrate** the changes in energy that occur in a refrigerator system.
3. **Explain** why it is difficult to cool down a fridge that has been left open.

Section 8.3 review

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Section 8.3 questions

Remembering

1. **Define** a 'system'.
2. **State** five examples of everyday systems that undergo energy changes.
3. **Identify** where on a car you would find the crumple zones and describe why they are located there.

Understanding

4. **Explain** why a seatbelt is needed to stop the occupant in a collision.
5. **Explain** why a real pendulum's motion is not infinite and will eventually come to a stop.

Applying

6. **Distinguish** between the forces felt by occupants in a car collision in a car with and without an airbag.

Analysing

7. When an object is dropped, energy is being transformed, and thus work is being done. However, for work to be done, a force needs to be applied to the object. **Propose** the force that is responsible for work being done.
8. Sports cars often have more crumple zones than other cars. **Propose** a reason for this.

Evaluating

9. **Justify** why heating vents are often positioned on the floor while air conditioner vents are usually closer to the ceiling.

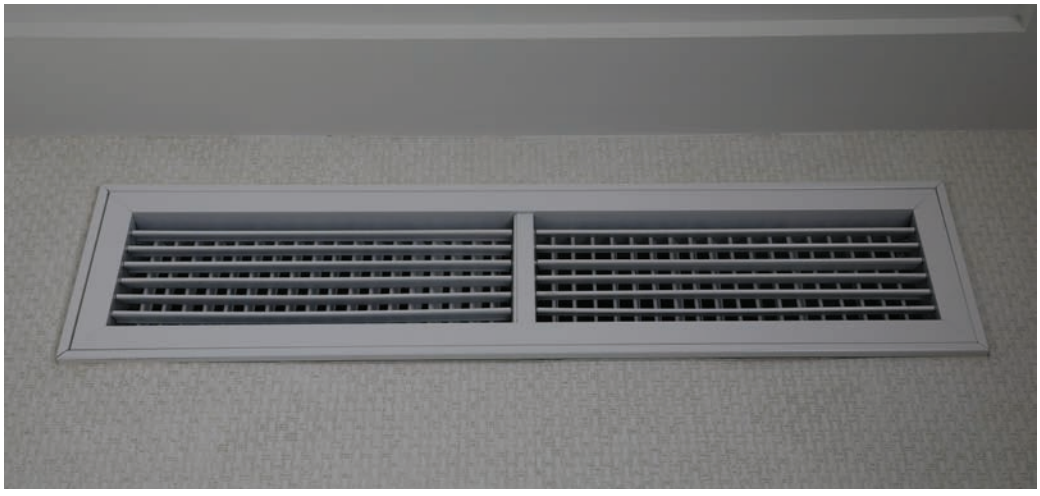

Figure 8.28 A floor heating vent

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Chapter review

Chapter checklist

Success criteria		Linked questions
8.1	I can recognise the relationship between energy and work.	3, 5
8.1	I can identify different forms of potential and kinetic energy.	1, 2
8.2	I can describe energy transfers and transformations.	6, 7, 9
8.2	I can calculate and illustrate the efficiency of energy transfers using a Sankey diagram.	9
8.3	I can consider energy in different systems.	4, 8

Go online to access the interactive chapter review

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **List** six different forms of energy, giving an example of (or where you would find) each.

Understanding

2. **Name** the two types or categories of energy into which all of the various forms of energy can be placed.
3. **Define** work qualitatively and quantitatively.
4. **Explain** how an airbag can reduce the impact of a collision on a person.

Applying

5. A worker carries some timber up a staircase. The worker moves 9.6 m vertically and 22 m horizontally. If the timber weighs 45 N, **calculate** how much work was done.
6. **Calculate** the efficiency of a blender that converts 200 J of electrical energy to 120 J of kinetic energy and 80 J of thermal energy per second.

Analysing

7. **Distinguish** between useful and wasted energy.
8. **Outline** how a refrigerator works.
9. A light bulb uses 60 J of electrical energy to produce 3 J of light energy. **Construct** a Sankey diagram that illustrates the amount of wasted energy and suggest what form this wasted energy will take.

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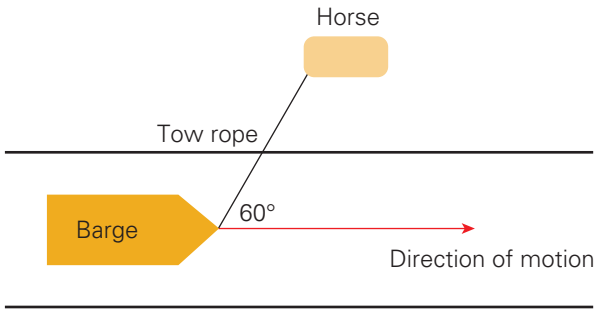
Evaluating

10. A barge (a long boat with a flat bottom) is pulled down a canal by a horse walking beside the canal. If the angle of the rope is 60°, as shown, the force exerted is 500 N, and the barge is pulled 50 m, **calculate** how much work the horse did in pulling the barge in the direction shown. (Hint: The component of the force in the direction of motion is given by $F\cos\theta$.)



Data questions

A tennis ball and golf ball are dropped from the same height and their first two bounces are recorded. The results are shown in Figure 8.29.

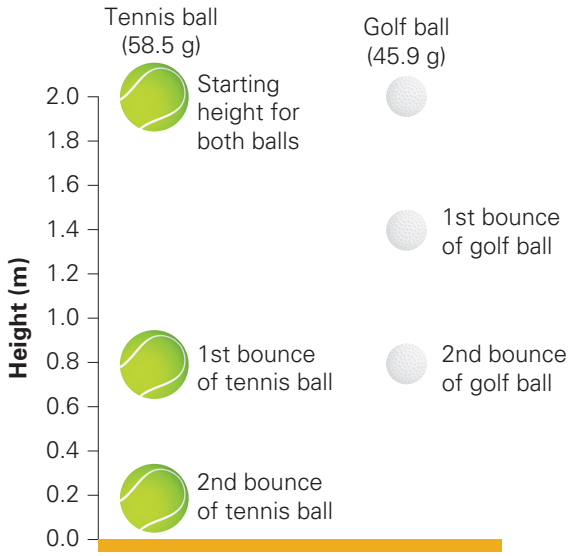


Figure 8.29 Dropping a tennis and golf ball from the same height and recording the heights of their first two bounces

1. Use the data from Figure 8.29 to **calculate** the missing weight and height information in the table.

Ball	Weight (kg)	Starting height (m)	Height of 1st bounce (m)	Height of 2nd bounce (m)	GPE at starting height (J)	GPE at 1st bounce (J)	GPE at 2nd bounce (J)
Tennis	0.0585	2	0.8	0.2			
Golf	0.0459	2	1.4	0.8			

2. **Contrast** the differences between the two balls to determine which is more efficient in converting gravitational potential energy to kinetic energy and back again.
3. **Extrapolate** from the data to predict how high the golf ball will reach on its third bounce.
4. **Infer** where the 'missing' energy has gone for both balls.
5. **Deduce** why the golf ball is more efficient than the tennis ball.

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STEM activity: Building a prototype to use the heat energy from the Sun

Background information

The Sun is the primary source of energy for our planet. Without the Sun, Earth would be a very different place. For example, almost all the water on the planet would be frozen; the constant darkness would make the process of photosynthesis impossible; there would be no sunsets, sunrises or seasons. In summary, life as we know it would not be possible on our planet.

Solar energy has been harvested by organisms on Earth for billions of years. All the diversity and beauty you see in our biosphere today started when small organisms began to photosynthesise.

Today, we use technology and advances in science to capture solar energy to power our modern society. Fossil fuels such as coal and gas, our most commonly used energy source, were created millions of years ago when solar energy was converted into plant mass in huge forests. Then, as plants died, their matter was deposited and covered by other sediments, creating coal and gas deposits.

However, we have recently developed technology capable of capturing solar energy through solar cells to produce electricity. In addition to this, technology using solar thermal (heat) energy to heat up water and generate electricity is being developed.

DESIGN BRIEF

Design a method of capturing thermal (heat) energy from the Sun and propose a method of using this energy in your school.

Activity instructions

In this activity, you and your colleagues will collaborate and build a prototype that uses the heat energy from the Sun and transforms this into a usable form.

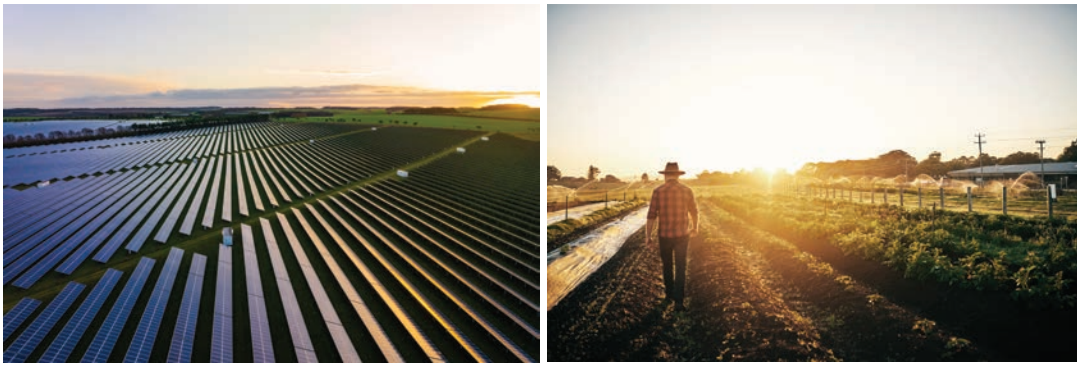

Figure 8.30 Solar energy has the potential to revolutionise the energy sector worldwide as we work towards mitigating the effects of climate change.

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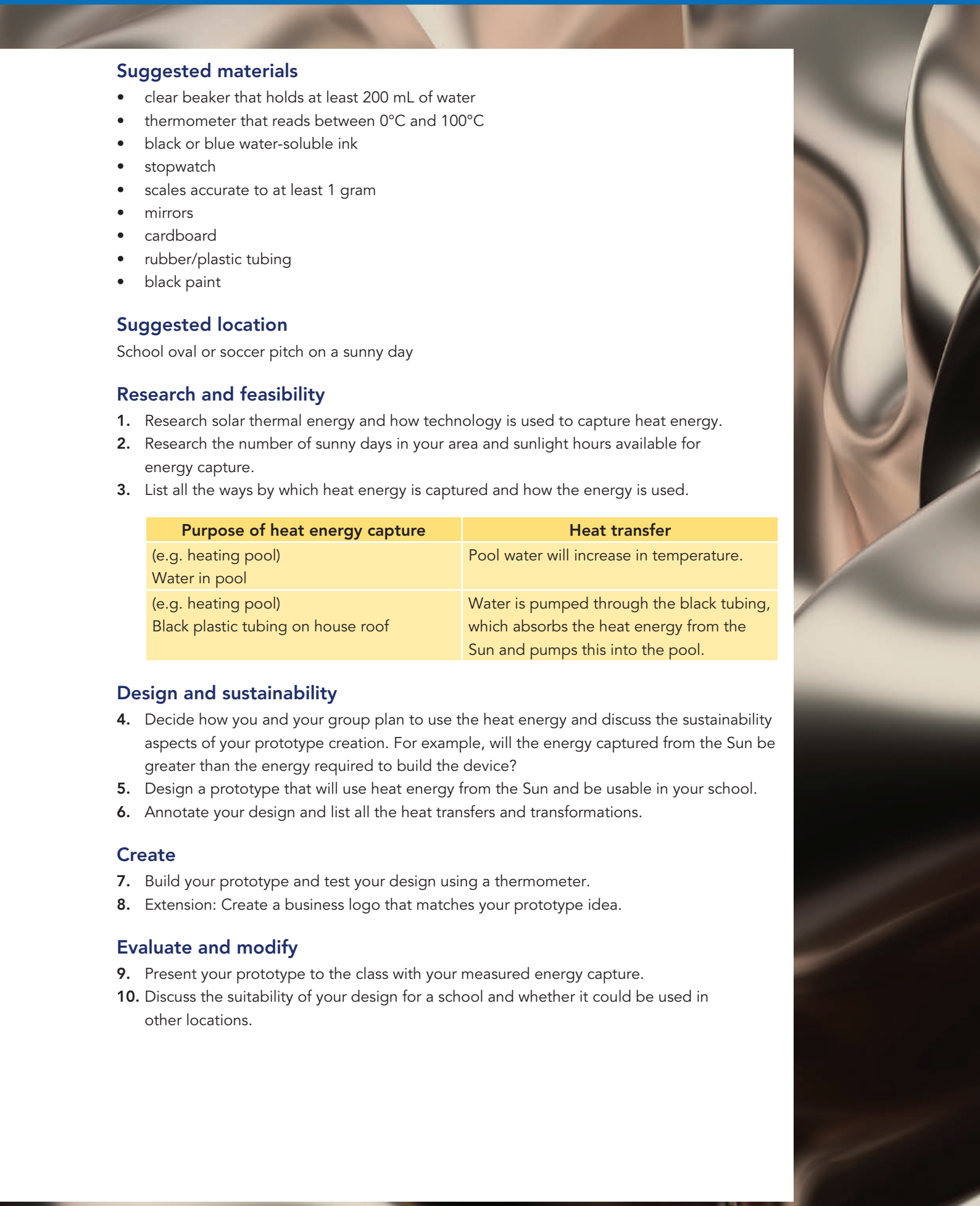

Suggested materials

- clear beaker that holds at least 200 mL of water
- thermometer that reads between 0°C and 100°C
- black or blue water-soluble ink
- stopwatch
- scales accurate to at least 1 gram
- mirrors
- cardboard
- rubber/plastic tubing
- black paint

Suggested location

School oval or soccer pitch on a sunny day

Research and feasibility

1. Research solar thermal energy and how technology is used to capture heat energy.
2. Research the number of sunny days in your area and sunlight hours available for energy capture.
3. List all the ways by which heat energy is captured and how the energy is used.

Purpose of heat energy capture	Heat transfer
(e.g. heating pool) Water in pool	Pool water will increase in temperature.
(e.g. heating pool) Black plastic tubing on house roof	Water is pumped through the black tubing, which absorbs the heat energy from the Sun and pumps this into the pool.

Design and sustainability

4. Decide how you and your group plan to use the heat energy and discuss the sustainability aspects of your prototype creation. For example, will the energy captured from the Sun be greater than the energy required to build the device?
5. Design a prototype that will use heat energy from the Sun and be usable in your school.
6. Annotate your design and list all the heat transfers and transformations.

Create

7. Build your prototype and test your design using a thermometer.
8. Extension: Create a business logo that matches your prototype idea.

Evaluate and modify

9. Present your prototype to the class with your measured energy capture.
10. Discuss the suitability of your design for a school and whether it could be used in other locations.

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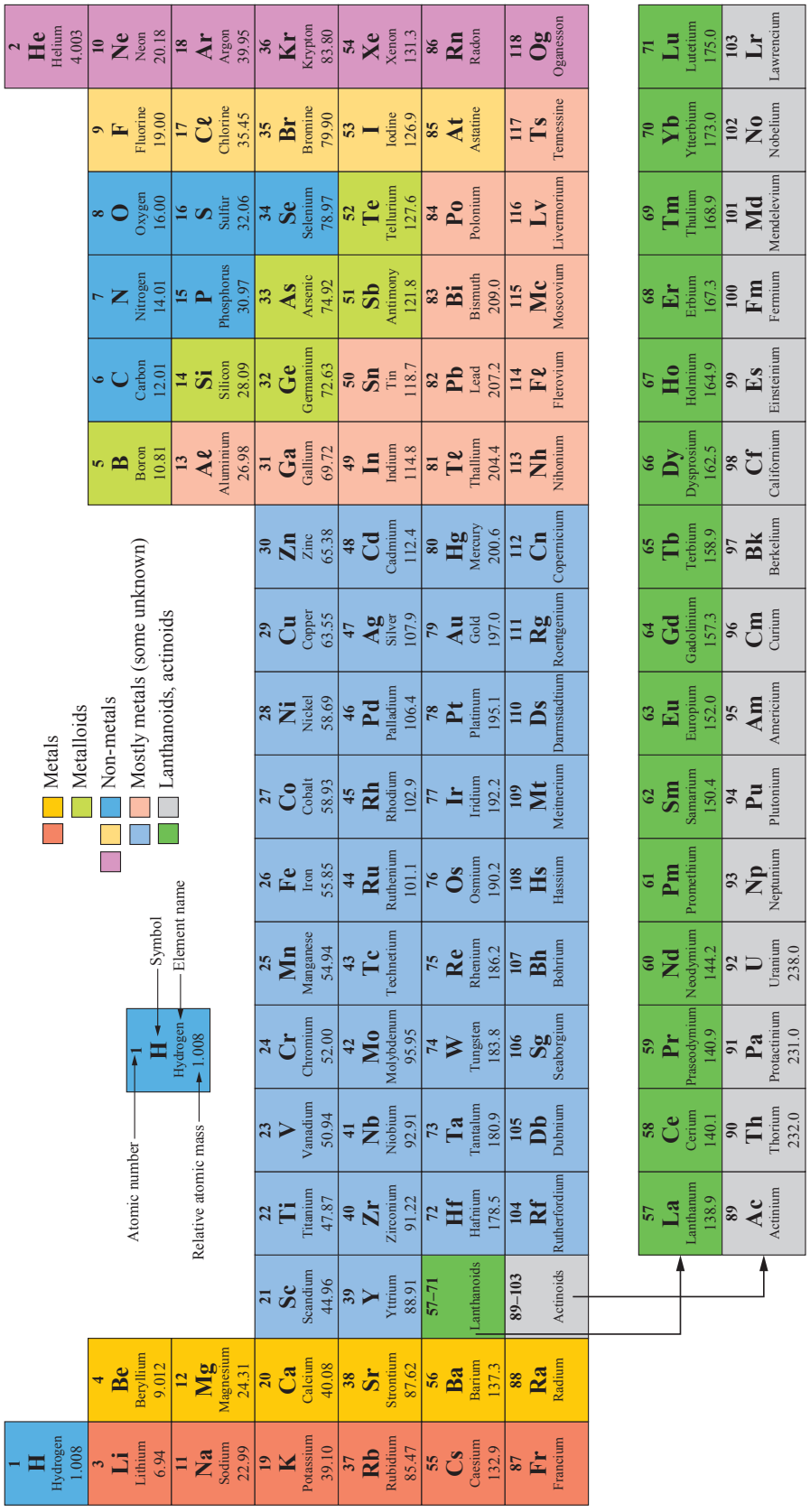
Appendix

The periodic table



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Glossary

Chapter 1: Science inquiry skills

absolute uncertainty the size of the range of values within which the actual 'true value' of a measurement probably lies

accuracy how closely measures match the 'true' or accepted values

bivariate analysis investigating the relationship between two variables to determine how changes in one variable might affect the other

confidentiality participants' data and results must be kept private

confounding variable an external factor that can unintentionally affect the outcome of an experiment, making it difficult to determine whether changes in the dependent variable are caused by the independent variable

controlled variable a factor that remains constant throughout an experiment to ensure that any changes observed in the dependent variable are solely due to the manipulation of the independent variable

correlation the relationship between two variables

cultural appropriation use of cultural knowledge or tradition without acknowledgement or consent

dependent variable the variable that is measured during an experiment (as it responds to the independent variable)

ethics the standards used to appraise and guide what is considered as acceptable conduct

fair test an experiment where all variables are kept constant except for the independent variable being tested

hypothesis an educated guess that can be tested through further experimentation

implicit bias when someone's personal opinions influence their judgment without them being aware of it

independent variable the variable that is deliberately changed during an experiment

inference to link an observation with past knowledge and assign meaning to the observation

informed consent where possible, participants are informed about the risks and procedures involved in an experiment, and they sign to say they agree to participate

investigable question a research question that can be answered through completing an experiment

mean the average value, found by adding all the values together and dividing by the number of values

median the middle value in an ordered data set, or the average of the two middle values if the set has an even number of observations

mode the most frequently occurring value in a data set

model a simplified representation of a real-world system or phenomenon used to understand, analyse or predict its behaviour

outlier an anomalous data value that does not seem to fit the rest of the data

parallax error a measurement taken that is not the true value due to the position of the object along various lines of sight

plagiarism the act of using another person's ideas, research or creative works without proper attribution, presenting them as your own

precision how closely repeated measures agree with each other

prediction a statement that describes what is expected to happen if the hypothesis is true

qualitative a form of data that is a descriptive measurement

quantitative a form of data that is a numerical measurement

random error an error caused by limitations of the measurement device or the observer and does not follow a regular pattern

reading error a reading or measurement that is not the true value

relative uncertainty the ratio of the absolute uncertainty and the reported value, often expressed as a percentage

reliability how repeatable, replicable and reproducible the results are

repeatability how well the results match up when the same scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

replicability how well the results match up when a different scientist repeats the experiment using the same conditions as the original experiment, in a different laboratory or field site

reproducibility how well the results match up when a different scientist repeats the experiment under different conditions to the original experiment, with a different method, equipment and laboratory or field site

right to withdraw the right for a participant to leave a study at any time for any reason

simulation a computer program that uses a model to replicate the behaviour of a system over time

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systematic error an error that occurs through a poorly calibrated device (consistently high or consistently low)

titration a procedure or technique used to determine the concentration of an unknown solution

univariate analysis examining the characteristics of a single variable to understand its distribution and key features

validating checking if something is accurate, correct or reliable

validity the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what is says it measures

variable a factor or condition that can be controlled, changed or measured in an experiment

zero calibration error a measuring instrument giving a non-zero reading when the true value should be zero

Chapter 2: Genetics

allele a different form of the same gene

aneuploidy the presence of an abnormal number of chromosomes in a cell

autosome any chromosome that is not a sex chromosome; in humans, these are chromosome pairs 1 to 22

base triplet (codon) a set of three nitrogenous bases that code for an amino acid

carrier an individual with an allele for a recessive condition but who does not have the condition due to being heterozygous

centromere a structure that holds two sister chromatids together

chromatin a mixture of DNA and proteins that forms chromosomes

chromosome a thread-like structure of tightly wound DNA and proteins

chromosome mutation a mutation involving large segments of DNA

codominance both alleles are expressed equally in the phenotype

complementary base pairing adenine only binds with thymine and cytosine only binds with guanine

crossing over the exchange of genetic material between homologous chromosomes during meiosis, leading to genetic diversity in gametes

deletion where a nucleotide is deleted from the DNA sequence

diploid (2*n*) a cell containing two sets of chromosomes

DNA deoxyribonucleic acid; the molecular unit of heredity, containing the genetic information responsible for the development and function of an organism

dominant a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

embryo the initial stage of early development in multicellular organisms

fertilisation the fusion of male and female gametes to form a zygote

filial describes the offspring of a cross

gametes sex cells (sperm and ova) with half the usual number of chromosomes

gene a length of chromosome made of DNA; the basic unit of inheritance

gene mutation a permanent alteration in the DNA sequence that makes up a gene

gene therapy a process by which a copy of a functional gene is introduced into an organism

genetic engineering deliberately modifying genetic material to manipulate the characteristics of an organism

genetic screening genetic tests carried out across the population to identify people at risk of genetic disorders

genetically modified organism an organism that has had its genome altered using genetic engineering techniques

genetics the study of genes, genetic variation and heredity

genome the complete set of genetic material in an organism

genotype the combination of alleles an organism has for a particular gene

germline mutation a mutation of DNA in gametes, which can be inherited

gonads the sexual organs: testes in males and ovaries in females

haploid (*n*) a cell containing only one set of unpaired chromosomes

heredity the passing on of traits genetically from one generation to the next

heterozygous having two different alleles at a particular gene locus

homologous chromosomes a matching pair of chromosomes, with one having been inherited from each parent; they have the same gene sequence and loci, length and centromere position

homozygous having two identical alleles at a particular gene locus

hydrogen bonds chemical bonds that hold the two DNA strands together

incomplete dominance a form of inheritance in which both alleles are partially expressed, producing a third intermediate phenotype

induced mutation a mutation produced by environmental factors

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insertion where one or more extra nucleotides are inserted into the DNA

inversion where two nucleotides reverse their order

karyotype the chromosomes of an individual, often displayed according to size and gene band patterns

locus (plural: loci) the location of a gene on a chromosome

meiosis the process by which the gonads make gametes, which are haploid

mitosis the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

monogenic a trait that is controlled by a single gene

monohybrid cross a type of genetic cross or breeding experiment that considers the inheritance of a single trait or characteristic that is typically controlled by a single gene with two alleles

monomer a single subunit that when joined together repeatedly makes a polymer

mutagenic causing mutations in DNA

mutation a change in the genetic code of a cell

non-disjunction the failure of homologous chromosomes or sister chromatids to separate correctly in meiosis

non-homologous chromosomes chromosomes that do not belong to the same pair

nucleotide a monomer subunit of a nucleic acid, consisting of a phosphate group bound to a five-carbon sugar, which in turn is bound to a nitrogenous base

ova (singular: ovum) mature female reproductive cells

pedigree a chart that shows relationships between family members and indicates which individuals have certain genetic traits

phenotype the observable characteristics of an organism, resulting from both genotype and the environment

point mutation a mutation in which a single nucleotide is changed

polymer a molecule made from many repeating subunits called monomers

polypeptide a chain of amino acids, forming part or the whole of a protein molecule

Punnett square a specialised grid to show genetic crosses

recessive a characteristic in which the allele responsible is only expressed in the phenotype if two copies of the allele are present

recombination the rearrangement of genetic material, especially by crossing over

reduction division cell division which results in a reduction of genetic material in the daughter cells

sex chromosomes chromosomes that determine the sex of an organism

sexual reproduction a form of reproduction that involves the fusion of gametes from two parents and introduces variation to the offspring

sister chromatids two copies of the same chromosome, connected at a centromere

somatic cells the body cells of an organism

somatic mutation a mutation that occurs in somatic (body) cells and that cannot be inherited

spontaneous mutation a naturally occurring mutation

stem cells undifferentiated cells with the ability to develop into various specialised cell types

substitution where one nucleotide is swapped for another

telomeres structures made from DNA and proteins that protect the ends of chromosomes

test cross a genetic cross between a homozygous recessive individual and an individual of unknown genotype showing the dominant trait to determine the unknown genotype

transcription the first stage of protein synthesis in which the base sequence of DNA is copied into mRNA

transgenic organism an organism that possesses a foreign gene or segment of foreign DNA in its genome because of human experimentation

translation the second stage of protein synthesis in which a sequence of mRNA is translated into a sequence of amino acids

trisomy when an organism has a third copy of a chromosome

zygote a fertilised egg produced by the fusion of male (sperm) and female (ovum) gametes

Chapter 3: Evolution

absolute dating determining the actual age of a material

adaptation a characteristic that contributes to an individual's ability to survive in its environment

allele frequency the relative proportion of a specific allele within a population

analogous structures structures that have a similar function but evolved separately

artificial selection intentional breeding of organisms with particular characteristics to produce offspring with more desirable traits

biodiversity the variety of life on Earth, including the diversity of species, the genetic differences within a species and the ecosystems where species are found

biogeography the study of the geographical distribution of plants and animals

biostratigraphy a branch of stratigraphy focused on dating rock layers using the fossils found in them

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biota all the living organisms found within a particular region or ecosystem

bottleneck effect the decrease in genetic diversity resulting from a rapid reduction in the size of a population due to events such as natural disasters or human activities such as overhunting

convergent evolution the process by which unrelated species independently evolve similar traits due to similar environmental pressures

direct (evidence) evidence that supports an assertion without intervening inferences

divergent evolution when closely related species evolve different traits, adapting to different environments or selection pressures from a common ancestral form

DNA hybridisation a technique that measures genetic similarity between two organisms

ecosystem diversity the variation in ecosystems in a given area

endangered a species that is in danger of becoming extinct

endemism a state of being confined to a small, defined geographic location

evolution change in the genetic composition of a population over successive generations, which may result in the development of new species

evolutionary tree a diagram used to represent evolutionary relationships between organisms

extinct a species that has no living members

fertile able to reproduce

fossil the shape or impression of a bone, a shell or a once-living organism that has been preserved for a very long period of time

fossil record the record of past life and evolution inferred from fossils

fossilisation the process of forming a fossil

founder effect the decrease in genetic diversity that occurs when a population is descended from a small population that separated from a larger one

gene flow the movement of genetic information from one population to another through migration

genetic diversity the number of different alleles of genes in a population

genetic drift the random change in allele frequencies in a population from generation to generation

genetic variation the differences in DNA sequences between individuals within a population

half-life the length of time needed for the radioactivity of a radioactive substance to be reduced by half

homologous structure a similar physical feature in organisms that have evolved from the same common ancestor

index fossil a fossil used as the basis for dating the strata it occupied

indirect (evidence) evidence that requires inferences to be made

mass extinction a rapid, widespread loss of biodiversity, with many species going extinct in a short timeframe

megafauna large animals with a body mass of over 45 kilograms

natural selection a process in which organisms whose phenotype is best adapted to their environment are more likely to survive and reproduce

population (ecological) a group of a particular species living and interbreeding in the same geographical area

radioisotope a radioactive isotope of a chemical element with an unstable nucleus that emits excess energy (radiation)

relative dating determining the order of past events without the specific age

reproductive isolation when members of two related populations can no longer interbreed

selection pressure a factor that affects the relative fitness or reproductive success of individuals within a population, leading to natural selection and potential changes in allele frequencies over time

selective advantage the characteristic of an organism that enables it to survive and reproduce better than other organisms in a population

selective breeding another term for artificial selection

speciation the process by which populations evolve to become distinct species

species a group of organisms consisting of similar individuals who can interbreed with one another

species diversity the number and abundance of different species in a given area

stratigraphy the branch of geology studying rock layers

trace fossil a trace of an animal, such as a footprint or imprint, that has become fossilised

variation the range of differences or diversity in traits, characteristics or genetic make-up among individuals

viable able to survive

Chapter 4: Chemical bonding

anion a negatively charged ion

bonding pair two valence electrons that are shared between two different atoms

cation a positively charged ion

chemical bond the association of two atoms due to the transfer of electrons between them or the sharing of valence electrons

covalent bond the formal sharing of a pair of valence electrons

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crystalline a perfect lattice structure without deformities

delocalised electron an electron that has become delocalised from an individual atom

diatomic a substance made up of two atoms bonded together

ductile able to be drawn into a wire

electron configuration the arrangement of an atom's electrons in the shells around the nucleus

electron shell the energy level in which the electrons orbit the nucleus of an atom

electrostatic attraction the force of attraction between positively and negatively charged particles

ground state the lowest energy level of an atom

ion an atom with a formal positive or negative charge due to the loss or gain of electron(s)

ionic bond the transfer of valence electrons from one atom to another, resulting in an electrostatic attraction between ions

lattice a three-dimensional structure in which atoms/ions are in fixed positions

lustrous in metals, having a shiny surface

malleable able to be hammered into sheets

metallic bond the electrostatic attraction between a lattice of metal cations and a 'sea' of delocalised electrons

metalloids elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

molecular compound atoms of different elements chemically combined with covalent bonds

molecular element atoms of the same element chemically combined with covalent bonds

molecular formula a symbol formula showing the number and type of each element covalently bonded together

molecule elements and compounds containing two or more atoms combined with covalent bonds

octet rule atoms tend to lose, gain or share outer shell electrons to achieve eight electrons in their outer shell

polyatomic ion a covalent molecule with an overall charge

transition metals the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

valence electrons the electrons in the outer shell of an element

valence shell the outermost shell of the atom that contains electrons

Chapter 5: Chemical reactions

acid a substance that, when dissolved in water, causes the pH of the solution to fall below 7

activation energy the minimum collision energy required to break and form bonds

agitating stirring, swirling or shaking a mixture

aqueous dissolved in water

base a substance that, when dissolved in water, causes the pH of the solution to rise above 7

catalyst a substance that speeds up a chemical reaction by lowering the energy needed to break and form bonds (activation energy), and does not get used up in the process

chemical equation a chemical reaction written using the symbols and formulas of the reactants and products involved

coefficient the number placed before a formula unit in a chemical equation to ensure it is balanced

collisions the violent coming together of two or more particles; a requirement for a chemical reaction to occur

concentrated solution a solution which contains a relatively large amount of solute compared to solvent

concentration the amount of solute dissolved in a solvent

diatomic a substance made up of two atoms bonded together

dilute solution a solution which contains a relatively small amount of solute compared to solvent

elementary entity a small particle such as an atom, compound, molecule or ion

insoluble a solute that does not dissolve in a solvent

metal displacement reaction when a more reactive metal removes a less reactive metal from its compound

molar mass the mass of one mole of an elementary entity

mole 6.02×10^{23} elementary entities

monatomic (also monoatomic) existing as one atom

neutralisation a reaction between an acid and a base, generally forming a solution that has a pH of 7

particle diagram a representation of elements and compounds where atoms are drawn as balls or circles

pH a scale of the degree of H^+ ion concentration in an aqueous solution

precipitation a reaction that involves the mixing of two solutions to produce a solid called a precipitate

pressure the force produced by collisions of gas particles per unit area of the container walls

products the chemicals produced in a reaction

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reactants the chemicals which react together in a reaction

reaction rate the quantity of reactant or product used up or made per unit of time; how quickly the reaction progresses

reactivity series a series of metals ordered by their observable reactivity, from highest to lowest

relative atomic mass the mass of the number of protons and average number of neutrons in an atom relative to carbon-12

salt an ionic compound produced in a chemical reaction

soluble a solute that dissolves in a solvent

surface area the area of the outer part or surface of an object

synthesis a reaction in which two (or more) elements or reactants combine to form new substances or products

thermal decomposition decomposition that occurs when a substance is heated

word equation a chemical reaction written using the names of the reactants and products involved

Chapter 6: Exploring the universe

absorption spectrum a spectrum showing dark lines representing specific wavelengths that have been absorbed by a substance

arcsecond 1/3600th of a degree

astronomical unit the distance between Earth and the Sun

B–V colour index the difference in brightness measured through blue and green filters, indicating the colour of a star

baseline a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

Big Bang the rapid expansion of matter that marked the origin of the universe

black hole the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing can escape, not even light

blue shift when a spectrum has shifted towards shorter wavelengths

constellation a group of stars as seen from Earth that appear to form a familiar shape

continuous spectrum all wavelengths within a specific range

cosmic microwave background electromagnetic radiation left over from the early stages of the universe

cultural lore the stories, customs, beliefs and spirituality of Aboriginal people, which is passed down through generations and acts as a guide for everyday life

dark energy a theoretical force responsible for accelerating the expansion of the universe

dark matter matter that does not emit light and is responsible for unidentified gravity in the universe

Doppler effect a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

emission spectrum a spectrum showing bright lines representing specific wavelengths that have been emitted by a substance

epoch of recombination the point in time when electrons and ions could combine to form atoms

exoplanet a planet outside our solar system, orbiting a star other than our Sun

galaxy a gravitationally bound system containing billions of stars and planets

geocentric a model of the solar system with Earth at the centre

Goldilocks zone the habitable zone around a star where the temperature is not too hot and not too cold

H–R diagram (Hertzsprung–Russell diagram) a graph where the star luminosity is plotted against temperature

heliocentric a model of the solar system with the Sun at the centre

Hubble's law the farther away a galaxy is from Earth, the faster it is moving away from us

interferometry a technique that uses the interference of waves to measure distances

light year the distance that light travels in one year (about 10 trillion km)

luminosity the intrinsic brightness of a celestial object

main sequence the phase during which stars convert hydrogen into helium in their cores

nebula (plural: nebulae) a cloud of gas and dust in space

neutron star a tiny, hot, dense star formed when a star explodes as a supernova; made only of neutrons

nuclear fusion the process of joining two nuclei to produce energy

observable universe the spherical region of the universe that can be observed from Earth or space telescopes; it encompasses everything close enough that light has had time to reach Earth

optical telescope a device that collects and focuses light from the visible spectrum to form an image

parallax the effect by which the position of an object seems to change when it is observed from different locations

parsec the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

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planetary nebula a type of nebula that forms as a result of a red giant throwing off its outer layers

plasma the ionised fourth state of matter, in which nuclei and electrons are separated

radio telescope a device that receives radio waves emitted by stars and other celestial objects

recessional velocity the rate at which a star is moving away from Earth

red giant a very large, bright, cool star that has run out of hydrogen in its core

red shift when a spectrum has shifted towards longer wavelengths

retrograde motion the apparent backward motion of a planet as seen from Earth

singularity a point at which infinitely dense matter occupies an infinitely small space

spectral class a group into which stars are classified based on their spectra

supernova the explosion of a massive star

white dwarf a small, dense, dim star that has lost its outer layers and is at the end of its lifetime

Chapter 7: Motion

acceleration (*a*) the change in velocity of an object over time

average speed change in distance over a time interval

average velocity the rate at which an object is displaced or changes position over a time interval

constant velocity when an object is travelling at the same speed without changing direction

deceleration when an object is slowing down

displacement (*s*) a vector quantity describing the distance and direction of an object from its origin

distance (*d*) a scalar quantity measuring the total length travelled

force any interaction that, when unopposed, will change the motion of an object

gradient in physics, how quickly something changes, or the rate of change; the gradient of a graph is calculated as the rise over the run

gravity the force by which a planet or other body draws objects towards its centre

inertia the tendency of an object to remain in its state of motion in the same direction unless acted upon by an external force

instantaneous speed the speed at a given point in time

instantaneous velocity the velocity of an object measured at a particular moment in time

mass the quantity of matter

net force the sum of all the forces acting on an object

Newton's first law of motion an object will remain at rest or moving at a constant speed in a straight line unless acted upon by an external force

Newton's second law of motion an object acted upon by a force experiences acceleration in the same direction proportional to the magnitude of the net force and inversely proportional to the mass of the object

Newton's third law of motion for every action, there is an equal and opposite reaction

origin the 0 point on the *y*-axis of a displacement–time graph

scalar a quantity having only magnitude

speed change in distance divided by time

stationary not moving

terminal velocity the maximum speed reached by a free-falling object

vector a quantity having both magnitude and direction

vector diagram a diagram showing the magnitude and direction of a vector quantity

velocity (*v*) change in displacement divided by change in time

weight the force of gravity on the mass of an object

Chapter 8: Conservation of energy

efficiency the percentage of input energy that is converted to useful energy by a machine

elastic potential energy energy stored in an object due to its shape, usually resulting from the object either being compressed or stretched

energy the ability to do work

gravitational potential energy energy stored in an object due to its position above the surface of Earth

kinetic energy energy possessed by an object due to its motion

law of conservation of energy a scientific law that states that energy can be neither created nor destroyed, only converted from one form of energy to another

potential energy energy that is stored in an object due to its position and other factors, such as its mass, electric charge and internal stresses

Sankey diagram a flow chart that represents the flow of energy through a system

system a portion of the universe that is being analysed

useful energy the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it produces

work the amount of energy transferred when an applied force causes an object to move some distance

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